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VIBRATION AND ACOUSTIC ENVIRONMENT OF AH-1G HELICOPTER

TECHNICAL REPORT AFFDL-TR-75-17

APRIL 1975

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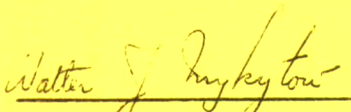
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This technical report has been reviewed and is approved for publication.

FOR THE COMMANDER

A handwritten signature in cursive script, reading "Walter J. Mykytow", written over a horizontal line.

WALTER J. MYKYTOW
Ass't. for Research and Technology
Vehicle Dynamics Division
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Abstract Continued.

levels (SPL) versus frequency. Amplitude probability density (APD) plots also are included. Measured vibration and acoustic data are compared with military standards and specification requirements.

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PREFACE

This effort was planned jointly by the Dynamics Technology Applications Branch, Vehicle Dynamics Division, Air Force Flight Dynamics Laboratory (AFFDL), Wright-Patterson AFB, Ohio, and the Mechanical Engineering Support Service Department, R & D Directorate, U.S. Army Electronics Command (ECOM), Fort Monmouth, New Jersey.

The investigation was conducted under Air Force Flight Dynamics Laboratory Project 1472, Dynamics Measurement and Analysis Technology for Military Vehicles, Task 147201, Dynamic Testing of Flight Vehicles, Work Unit 147201-03, Vibration and Acoustic Studies on Helicopters; and under internal U.S. Army Electronics Command, Engineering Support Services Department, R & D DA Task number 1H6 34301 D2440501, Airborne Shock and Vibration Study Program.

The helicopter was provided by the U.S. Army Electronics Command (USAECOM), Fort Monmouth, New Jersey. The helicopter was piloted by Major Jim Basta of USAECOM (SELHI-AV-0) at Lakehurst, New Jersey, and Mr. James Garner of the Army Airfield Division, (STEAP-AV) at the Aberdeen Proving Ground, Maryland.

This report was submitted by the authors in August 1974.

TABLE OF CONTENTS

<u>SECTION</u>		<u>PAGE</u>
I	INTRODUCTION	1
II	DISCUSSION	2
	A. Vehicle Description	2
	B. Instrumentation	2
	C. Flight Measurement Procedures	3
	D. Data Reduction Procedures	4
	E. Data Presentation	6
III	RESULTS	10
	A. General	10
	B. Amplitude Probability Density	10
	C. Summary Plots for the Entire Helicopter	11
	D. Summary Plots for the Helicopter Zone	11
	E. Group Plots for Specific Transducer Locations	12
	F. Sound Pressure Levels	17
IV	CONCLUSIONS	19
V	RECOMMENDATIONS	20
	REFERENCES	27

LIST OF ILLUSTRATIONS

<u>Figure</u>		<u>Page</u>
	<u>Photographs and Drawings</u>	
1	AH-1G Helicopter, S/N 67-15711 with Armament	28
2	Piezoelectric Accelerometer Locations	29
3	Low Frequency Accelerometer Locations	30
4	Microphone Locations	31
5	Percentile Plot Illustration	32
	<u>APD Plots, Standard Inputs</u>	
6	Sinusoidal Input	33
7	Random Gaussian Input	34
8	Ratio of Random to Sinusoidal Component of 1:1	35
9	Ratio of Random to Sinusoidal Component of 1:2	36
10	Ratio of Random to Sinusoidal Component of 1:5	37
	<u>APD Plots, F & A Vibration, Pilot's Pedestal, Sta. 122</u>	
11	Level Flight, 42 Hz Center Frequency	38
12	Level Flight, 204 Hz Center Frequency	39
13	Level Flight, 412 Hz Center	40
14	Gunfire, 4000 SPM, 22 Hz Center Frequency	41

LIST OF ILLUSTRATIONS - Cont'd

<u>Figure</u>			<u>Page</u>
15		Gunfire, 4000 SPM, 192 Hz Center Frequency	42
16		Gunfire, 4000 SPM, 446 Hz Center Frequency	43
17		Rocket Salvo, 6 SPS, 105 Hz Center Frequency	44
18		Rocket Salvo, 6 SPS, 520 Hz Center Frequency	45
19		Rocket Salvo, 6 SPS, 1028 Hz Center Frequency	46
	W/O	With	
	Gunfire	Gunfire	
		<u>Acceleration & PSD Plots, Entire Helicopter</u>	
20	21	Acceleration, ALL Accelerometers	47/48
22	23	PSD, ALL Accelerometers	49/50
		<u>Acceleration Zone Plots, ALL Accelerometers</u>	
24	25	Nose Section and Cockpit	51/52
26	27	Engine-transmission Section	53/54
28	29	Aft Electrical and Radio Sections	55/56
30	31	Aft Tail Boom Section	57/58
		<u>PSD Zone Plots, ALL Accelerometers</u>	
32	33	Nose Section and Cockpit	59/60
34	35	Engine-transmission Section	61/62
36	37	Aft Electrical and Radio Sections	63/64
38	39	Aft Tail Boom Section	65/66

LIST OF ILLUSTRATIONS - Cont'd

<u>Figure</u>			<u>Page</u>
W/O	With		
Gunfire	Gunfire		
<u>Acceleration Group Plots, Piezoelectric Accelerometers</u>			
40	41	Gunner's Instrument Panel, Left Side, Sta.60	67/68
42	43	Gunner's Pedestal, Left Side, Sta.65	69/70
44	45	Gunner's Pedestal, Right Side, Sta.77	71/72
46	47	Gunner's Instrument Comp., Right Side, Sta.73	73/74
48	49	Gunner's Floor, Center, Sta.66	75/76
50	51	XM-28 Turret Interface, Sta.69	77/78
52	53	Pilot's Floor, Center, Sta.134	79/80
54	55	XM-28 Turret, Center, Sta.77	81/82
56	57	Pilot's Instrument Panel, Right Side, Sta.115	83/84
58	59	Pilot's Pedestal, Left Side, Sta.122	85/86
60	61	Pilot's Instrument Comp., Left Side, Sta.122	87/88
62	63	Pilot's Instrument Comp., Right Side, Sta.130	89/90
64	65	Pilot's Pedestal, Right Side, Sta.136	91/92
66	67	Main Transmission Mount, Left Front, Sta.188	93/94
68	69	Main Transmission Mount, Right Rear, Sta.202	95/96
70	71	Engine Mount, Left Side, Sta.244	97/98
72	73	Right Wing, Top Outboard, Sta.191	99/100
74	75	Right Wing, Top Inboard, Sta.186	101/102
76	77	UHF-VHF Antenna Comp., Sta.179	103/104
78	79	FM Antenna Comp., Sta.238	105/106

LIST OF ILLUSTRATIONS - Cont'd

<u>Figure</u>			<u>Page</u>
W/O Gunfire	With Gunfire		
80	81	Aft Electrical Comp., near AN/ARN-83 Direction Finder, Sta.279	107/108
82	83	Aft Electrical Comp., near AN/ASN-43 Gyro Compass, Sta.291	109/110
84	85	Structure near AN/APX-72 Transponder, Sta.330	111/112
86	87	Tail Boom, Sta.400	113/114
88	89	Radio Comp., near AN/ARC-51 Transceiver, Sta.346	115/116
90	91	Radio Comp., near AN/ARC-134 Transceiver, Sta.364	117/118
92	93	Tail Boom near 45° Gear Box, Sta.470	119/120
94	95	Tail Boom near 90° Gear Box, Sta.520	121/122
<u>Acceleration Group Plots, Low Frequency Accelerometers</u>			
96	97	Gunner's Instrument Panel, Left Side, Sta.60	123/124
98	99	Gunner's Floor, Sta.68	125/126
100	101	Pilot's Instrument Panel, Right Side, Sta.115	127/128
102	103	Pilot's Floor, Left Side, Sta.134	129/130
104	105	Pilot's Floor, Right Side, Sta.134	131/132
106	107	Aft Electrical Comp., near AN/ASN-43 Gyro Compass, Sta.284	133/134
108	109	Tail Boom near 90° Gear Box, Sta.524	135/136

LIST OF ILLUSTRATIONS - Cont'd

<u>Figure</u>			<u>Page</u>
W/O Gunfire	With Gunfire		
<u>PSD Group Plots, Piezoelectric Accelerometers</u>			
110	111	Gunner's Instr. Panel, Left Side, Sta.60	137/138
112	113	Gunner's Pedestal, Left Side, Sta.65	139/140
114	115	Gunner's Pedestal, Right Side, Sta.77	141/142
116	117	Gunner's Instr. Comp., Right Side, Sta.73	143/144
118	119	Gunner's Floor, Center, Sta.66	145/146
120	121	XM-28 Turret Interface, Sta.69	147/148
122	123	Pilot's Floor, Center, Sta.134	149/150
124	125	XM-28 Turret, Center, Sta.77	151/152
126	127	Pilot's Instr. Panel, Right Side, Sta.115	153/154
128	129	Pilot's Pedestal, Left Side, Sta.122	155/156
130	131	Pilot's Instr. Comp., Left Side, Sta.122	157/158
132	133	Pilot's Instr. Comp., Right Side, Sta.130	159/160
134	135	Pilot's Pedestal, Right Side, Sta.136	161/162
136	137	Main Trans. Mount, Left Front, Sta.188	163/164
138	139	Main Trans. Mount, Right Rear, Sta.202	165/166
140	141	Engine Mount, Left Side, Sta.244	167/168
142	143	Right Wing, Top Outboard, Sta.191	169/170
144	145	Right Wing, Top Inboard, Sta.186	171/172
146	147	UHF-VHF Antenna Comp., Sta.179	173/174
148	149	FM Atenna Comp., Sta.238	175/176
150	151	Aft Electrical Comp., near AN/ARN-83 Direction Finder, Sta.279	177/178

LIST OF ILLUSTRATIONS - Cont'd

<u>Figure</u>			<u>Page</u>
W/O Gunfire	With Gunfire		
152	153	Aft Electrical Comp., near AN/ASN-43 Gyro Compass, Sta.291	179/180
154	155	Structure near AN/APX-72 Transponder, Sta.330	181/182
156	157	Tail Boom, Sta.400	183/184
158	159	Radio Comp., near AN/ARC-51 Transceiver, Sta.346	185/186
160	161	Radio Comp., near AN/ARC-134 Transceiver, Sta.364	187/188
162	163	Tail Boom near 45° Gear Box, Sta.470	189/190
164	165	Tail Boom near 90° Gear Box, Sta.520	191/192
<u>PSD Group Plots, Low Frequency Accelerometers</u>			
166	167	Gunner's Instr. Panel, Left Side, Sta.60	193/194
168	169	Gunner's Floor, Sta.68	195/196
170	171	Pilot's Instr. Panel, Right Side, Sta.115	197/198
172	173	Pilot's Floor, Left Side, Sta.134	199/200
174	175	Pilot's Floor, Right Side, Sta.134	201/202
176	177	Aft Electrical Comp., near AN/ASN-43 Gyro Compass, Sta.284	203/204
178	179	Tail Boom near 90° Gear Box, Sta.524	205/206

LIST OF ILLUSTRATIONS - Cont'd

<u>Figure</u>			<u>Page</u>
W/O	With		
Gunfire	Gunfire		
<u>SPL Plots</u>			
180	181	Gunner's Helmet, Sta.90	207/208
182	183	Pilot's Helmet, Sta.140	209/210
184	185	Aft Electrical Comp., Sta.284	211/212
186	187	Radio Comp., Sta.390	213/214
188	189	Canopy Top, Outside, Sta.58	215/216
190	191	Canopy Top, Outside, Sta.103	217/218
192	193	Tail Boom Top, Outside, Sta.333	219/220
194	195	Tail Boom Top, Outside, Sta.393	221/222
196	197	Tail Boom Top, Outside, Sta.458	223/224
198	199	Nose, Bottom, Outside, Sta.54	225/226
200	201	Wing, Right, Outside, Sta.184	227/228
202	203	Below Aft Elec. Comp., Outside, Sta.287	229/230

LIST OF TABLES

<u>Number</u>		<u>Page</u>
I	Analyzer Performance Characteristics	5
II	Transducer Locations	21
III	Flight Conditions Selected for Data Reduction	25

SECTION I

INTRODUCTION

This report presents AH-1G Helicopter vibration and acoustic data obtained from the third of the three flight surveys planned jointly by the Air Force Flight Dynamics Laboratory and the U.S. Army Electronics Command. The complete helicopter vibration and acoustic study program included surveys on the UH-1C and the OH-6A Helicopters; those findings were reported in AFFDL-TR-73-160 and AFFDL-TR-74-81, respectively. The objectives of the helicopter study program are to obtain vibration, acoustic, and shock data suitable for (1) establishing realistic test methodologies for helicopter avionics and electronic equipment, (2) developing and verifying vibration prediction methods applicable to rotor powered aircraft, (3) updating specifications, and (4) obtaining human acoustical environmental data.

SECTION II
VEHICLE DESCRIPTION, INSTRUMENTATION, FLIGHT MEASUREMENT
PROCEDURES, DATA REDUCTION AND PRESENTATION

A. VEHICLE DESCRIPTION

The AH-1G Tactical Helicopter (SN 67-15911), shown in Figure 1 and manufactured by Bell Helicopter Company, is a tandem, two place, high speed conventional helicopter designed specifically for the combat role. The mission profiles completely cover the air-to-ground environment with suppressive fire at an area, attacking both light and hard point targets, while maintaining a fast, light, highly maneuverable helicopter. Its gross weight for takeoff, at sea level, on a NASA standard day is 9,500 pounds. It is powered by a T53-L-13 shaft turbine engine that has a sea level uninstalled military rated power of 1,400 shaft horsepower. In this installation, the engine is torque limited by the pilot to 50 psi torque for military and normal power at 6,600 rpm. Main rotor and tail rotor speeds with power on is 234 to 324 and 1500 to 1654 rpm, respectively. The fundamental frequencies of the main and tail rotors at normal power are 11 Hz and 59 Hz, respectively.

B. INSTRUMENTATION

Flight instrumentation consisted of (1) eight-four Endevco Corporation 2200 Series piezoelectric accelerometers, (2) twelve Gulton Industries Model LA 550203 low frequency accelerometers, (3) twelve Gulton Industries Model MA 299507 piezoelectric microphones, (4) a twelve-channel, nine-position selector switch, (5) a thirteen-channel signal conditioning box utilizing Fairchild Model ADO-24 operational amplifiers with external circuitry to obtain continually adjustable gains, (6) a voice microphone, (7) a magnetic pickup for indicating rotor position and speed, and (8) a fourteen-channel (Genisco, Inc., Model 10-110) tape recording system utilizing 30 in/sec tape speed, and 54K Hz center frequency record amplifiers.

The eighty-four piezoelectric accelerometers were mounted at twenty-eight points of interest, in groups of three, and oriented to sense

vibration along the three major axes of the helicopter. Low frequency accelerometers were mounted on the gunner's and pilot's instrument panels and floors, in the aft electrical compartment, and on the tail boom near the tail rotor. Microphones were mounted on the gunner's and pilot's helmets, at two locations in the aft electrical compartment, externally at five locations on top of the helicopter, and externally on top of the right wing, below the nose and below the aft electrical compartment. A complete listing of all pickup (accelerometer and microphone) identification numbers and types, and their locations, is contained in Table II. Figures 2, 3, and 4 are drawings showing locations of piezoelectric accelerometers, low frequency accelerometers, and microphones, respectively.

All accelerometers were calibrated in the laboratory using the same length cables and mounting brackets used during flight measurements. Accelerometer calibrations were conducted using a Calidyne Model 182 vibration exciter and an Unholtz-Dickie Model 610 Dial-A-Gain vibration monitor. The microphones were calibrated in the helicopter using a General Radio type 1552B calibrator. The frequency responses of the three types of pickups are summarized as follows:

Endevco Accelerometers: Flat within $\pm 0.05\text{dB}$ from 2000-6000 Hz.

Low Frequency Accelerometers: Flat within $\pm 0.5\text{dB}$ from 0-60 Hz
and within $\pm 3\text{dB}$ to 160 Hz.

Microphones: Flat within $\pm 2\text{dB}$ from 2000-6000 Hz and within
 $\pm 3\text{dB}$ to 10K Hz.

C. FLIGHT MEASUREMENT PROCEDURES

Flight measurements without armament fire were conducted on AH-1G Helicopter Serial No. 67-15711 at Lakehurst Naval Air Station, New Jersey. Measurements with armament fire were conducted at Aberdeen Proving Ground, Maryland. Test conditions without armament fire included ground runup, taxi, takeoff, climb, level flight at various speeds and altitudes, hover, descent, autorotation, combat approach to landing, and 30° and 60° turns.

Measurements also were made during gunfire at 2000 shots per minute (SPM) from wing mounted guns and at 2000 and 4000 SPM from the nose turret guns, rocket fire from both inboard and outboard rocket launchers, and grenade fire from the nose turret. Nose turret guns and the nose turret grenade launcher were both fired straight ahead as well as 40° down and 90° to the left and right.

Table III contains a listing of the flight conditions selected for data reduction.

For each flight condition, a twelve-channel data sample of approximately 20 seconds duration was recorded for each of the nine selector switch positions. Thus, the output of each of the 108 transducers was recorded for each flight condition. For some of the armament fire conditions, only a portion of the pickup outputs was recorded. A description of the location and direction of each pickup is shown in Table II. Flight conditions and aircraft performance parameters were recorded on a voice channel. Recorded information included altitude, airspeed, rate of climb, or descent, pitch angle, roll angle, engine speed, torque pressure, and outside air temperature. The output from the rotor speed/position pickup was superimposed on the voice channel.

D. DATA REDUCTION PROCEDURE

Five-second loops of flight recordings were dubbed from the tape reels using the Honeywell Record/Reproduce System. Exceptions to this were the loops of armament fire tapes, which were of shorter duration due to the time limitations (2 to 3 seconds) of continuous armament fire. Accelerometer data were played back on a Honeywell loop machine and analyzed on a Honeywell Model 9050, six-channel automatic wave analyzer. The analyzer performance characteristics are shown in Table I.

TABLE I
ANALYZER PERFORMANCE CHARACTERISTICS

<u>Effective Bandwidth (Hz)</u>	<u>Frequency Range (Hz)</u>	<u>True Averaging Time (Sec)</u>	<u>Scan Rate Hz/Sec</u>
6	0-160	4.7	0.5
25	161-1000	2.0	4.0
100	1001-6000	0.5	25

The analyzers produced plots of voltage versus frequency on six modified strip-chart recorders in the frequency range of 0-6000 Hz. Data points were manually extracted at each frequency marker (each 20 Hz from 0 to 400 Hz; each 50 Hz from 401 to 1000 Hz; each 100 Hz from 1001 to 2000 Hz; and each 200 Hz from 2001 to 6000 Hz). Significant peaks in the spectra at other frequencies were also tabulated. Overall voltages from each accelerometer were read on an rms voltmeter and tabulated.

The microphone data was analyzed on a General Radio Type 1921 Real-Time Analyzer equipped with one-third octave band filters covering the frequency range of 3.15 Hz to 10K Hz. The summed output of all one-third octave filters was provided for obtaining the overall sound pressure level (SPL). An integrating time of 4 seconds was used for analyzing records without armament fire. Since armament fire records were less than 4 seconds duration, an integrating time shorter than the record length (1 or 2 seconds) was used. The real-time analyzer output was tabulated on a Mohawk Data Sciences Model 800 high-speed printer.

The tabulated voltages from the Honeywell analyzers and the SPL amplitudes from the General Radio real-time analyzer and other identifying information were punched into IBM data cards. Corresponding decks of "master" cards containing descriptive information on pickup identification and sensitivity, flight conditions, and vibration sources were also

produced. The IBM card information together with formulas for calculating acceleration in gravitational (g) units and power spectral density in g^2/Hz were fed to an IBM 7094 computer. Formulas for these calculations are as follows:

$$g_p = SV \quad (1)$$

where g_p is the peak sinusoidal acceleration in g's, S is the accelerometer sensitivity in g_p per volt rms, and V is the number of rms volts read from the analyzer chart.

$$\text{PSD} = \frac{g_{\text{rms}}^2}{\text{BW}} \quad (2)$$

where PSD is the power spectral density, g_{rms} is the root-mean-square acceleration in g's and BW is the analyzer effective bandwidth in Hertz.

Plot tapes were then generated by the IBM 7094 computer, which were used with a Calcomp Model 563 automatic plotter to obtain finished plots of acceleration, PSD, and sound pressure level versus cycle frequency.

Amplitude probability density analyses of selected accelerometer outputs were conducted with a Gulton Industries, Inc., statistical analyzer. The Gulton analyzer controls were adjusted to obtain an amplitude range of ± 3 standard deviation units, a smoothing time constant of 3 seconds, and a scanning time from -6 to +6 standard deviation units of 900 seconds. The analog outputs of the analyzer (probability density versus amplitude) were plotted on a Mosley 2DR-2, X-Y recorder. APD plots of narrow band filtered acceleration signals were obtained. Narrow band filtering was accomplished with Spectral Dynamics SD-101A analyzers. Filter bandwidths of 5, 10, and 20 Hz were used in the frequency ranges of 5 to 100, 101 to 200, and 201 to 6000 Hz, respectively.

E. DATA PRESENTATION

Amplitude probability density data are presented directly as obtained from the Gulton Analyzer. Other vibration data are presented in two forms: (1) acceleration versus frequency, and (2) power spectral density versus frequency. Low frequency and piezoelectric accelerometer data

are plotted in the frequency range of 5 to 160 Hz and 5 to 6000 Hz, respectively. Sound pressure levels in dB (re 0.0002 dynes/cm²) are plotted in one-third octave bands in the frequency range of 3.15 to 10,000 Hz.

Each acceleration or PSD plot in this report portrays a summary of vibration amplitudes measured under all flight conditions except gunfire or during gunfire, by all transducers in one group, in one zone, or on the entire helicopter. Each group plot summarizes the data from either a group of three piezoelectric accelerometers measuring vertical, lateral, and fore and aft vibration, or a group of either two or three low frequency accelerometers. Zone plots cover the nose and cockpit sections, the engine transmission section, aft electrical radio sections, and the aft tail boom section of the helicopter.

In summarizing the data for vibration plots, the frequency range is first divided into bands approximately one-third octave wide. Then all data points (acceleration and PSD values) without regard to direction of vibration and for all flight conditions without gunfire (or with gunfire) are obtained for each group, zone, or entire helicopter for each frequency band. In the frequency range of 5 to 129 Hz these frequency bands are: 5-6, 7-8, 9-10, 11-13, 14-16, 17-20, 26-32, 33-39, 40-49, 50-64, 65-79, 80-99, and 100 to 129 Hz. In other frequency decades, the frequency bands are related to those listed above by factors of ten, but only up to 6400 Hz.

The data points in each frequency band are processed to obtain "percentile" type plots. Each percentile plot contains curves encompassing 99% and 90% of the data points as well as maximum, average, and minimum levels. The maximum and minimum points for each frequency band are simply the maximum and minimum points obtained from any one accelerometer. The average point in a band is obtained by summing the magnitudes of all data points and dividing by the number of points in the band. Points for the 99% curve are calculated from the equation,

$$P_{0.99} = [0.01N + 1]$$

where $P_{0.99}$ is the magnitude rank of the 99% data point in descending order from the maximum data point, and N is the total number of data points in a frequency band. The brackets inclosing the right side of the equation denote the greatest integer function value of $P_{0.99}$ (the decimal part is truncated). Points for the 90% curve are calculated from the similar equation:

$$P_{0.90} = [0.1N + 1]$$

Figure 5 illustrates examples of calculated percentile points for two values of N , 49 and 300. The symbol a_i in the figure denotes the i^{th} acceleration of data points in descending order from a_1 , the maximum data point, to a_μ , the minimum data point in a frequency band ΔF .

In the first frequency band of Figure 5, which contains 300 data points,

$$P_{0.99} = [0.01 (300) + 1] = 4$$

therefore, the acceleration data point of the 99% level is equal to that of a_4 , the fourth largest acceleration data point in the frequency band. Similarly,

$$P_{0.90} = [0.1 (300) + 1] = 31$$

and the acceleration of the 90% level is that of a_{31} .

In the second band, where there are only 49 data points,

$$P_{0.99} = [0.01 (49) + 1] = [0.49 + 1] = 1$$

and the 99% level coincides with the maximum acceleration data point, a_1 . This will always be the case if there are less than 100 data points, and obviously, no lower ranking data point will encompass the amplitudes of 99% of the **data** points. This calculation also illustrates an example of truncating the decimal part of the 0.99 to obtain the proper integral data point. If other values of N are assumed, the percentile equations will always yield the data point with the acceleration data point that is equal to or exceeds 90% of the data points, as desired.

Sound pressure levels for all flight conditions except gunfire also are plotted in the percentile type form. Since only one recording was made of the sound pressure levels during gunfire, the percentile type plot is not applicable to the gunfire sound plots.

Separate plots are made for (1) all flight conditions without gunfire, and for (2) gunfire, rocket salvo, and grenade salvo. Plots labeled "gunfire" may also include rocket and grenade salvo.

Both acceleration and PSD plots, with and without gunfire were prepared for each accelerometer. However, since there are a total of 394 of these, and since most recipients of the report will not require this much data, they are not included in this report. Copies of these plots may be obtained by request to the Air Force Flight Dynamics Laboratory, ATTN: FYT, Wright-Patterson AFB, Ohio 45433.

SECTION III

RESULTS

A. GENERAL

In the following discussion of results, reference is made to vibration amplitudes in various frequency bands. These vibration amplitudes obviously are dependent on analyzer bandwidths. In applying these data to the development of test criteria the bandwidths defined in Section II D should be considered. Also the predominantly random nature of the vibration above approximately 400 Hz should influence criteria derived from these data.

B. AMPLITUDE PROBABILITY DENSITY

Knowledge of the relative levels of sinusoidal and random components of the flight-vibratory environment is necessary for the development of appropriate vibration testing criteria. The shapes of APD plots of flight vibration are utilized in this report to evaluate the sinusoidal versus random content of measured vibration. Standard APD plots of sinusoidal, random, and mixtures are included. The characteristic shapes for a sine wave and for a random Gaussian signal are illustrated in Figures 6 and 7, respectively. APD plots were prepared for a mixture of a 100 Hz sine wave and a random signal having a flat spectrum from 20 to 1000 Hz. Figures 8-10 show that the random component must be reduced to less than the sinusoidal component before the shape of the APD plot differs appreciably from that for a pure random plot. The random component was reduced to one-fifth that of the sinusoidal component before the shape of the APD plot appeared to be more sinusoidal than random. Thus, the APD plot is a sensitive indicator of the presence of random components, but it is a relatively insensitive indicator of sinusoidal components.

Figure 11-19 are APD plots of vibration measured on the Pilot's Pedestal during level flight at 150 KIAS or during gunfire at 4000 SPM or rocket salvo at 6 SPS. APD plots were obtained for other locations and flight conditions, but since they duplicate the results illustrated

in Figures 11-19, they are not included here. Comparison of the APD plots of Figures 11-19 with mixed sinusoidal and random plots shows that the AH-1G helicopter vibration is predominantly sinusoidal in frequency bands up to 400 Hz. Vibration generally is more nearly random than sinusoidal in frequency bands above 400 Hz. These statements are true for all flight conditions including gunfire.

C. SUMMARY PLOTS FOR THE ENTIRE HELICOPTER

Figures 20-23 are summary plots of acceleration versus frequency for the entire helicopter. The sinusoidal vibration test curve for equipment designed for helicopters, from MIL-STD-810B, Reference 1 (Figure 514-1, Curve M), is superimposed on these plots. Figures 20 and 21 show piezoelectric accelerometer data for all flight conditions without gunfire, and for gunfire, respectively.

For Figures 20 and 21, in the frequency range of 10 to 160 Hz, about half the data points of the maximum vibration acceleration amplitudes exceed the MIL-STD-810B test curve. In the frequency range of 160 to 500 Hz, most of the maximum acceleration amplitudes contained in Figure 21 exceed the MIL-STD-810B test curve. Although the MIL-STD-810B test curve extends to only 500 Hz, Figures 20 and 21 illustrate that maximum acceleration levels of 4g to 25g are experienced in the frequency range of 500 to 6.4 Hz.

Since the PSD plots for the entire helicopter, Figures 21 and 22, repeat the data contained in the acceleration plots, but in a different form, they are not discussed in detail. The PSD plots are appropriate for random data presentation and are included for their potential use in deriving random vibration test criteria.

D. SUMMARY PLOTS FOR THE HELICOPTER ZONE

Figures 24-31 are acceleration zone plots for the nose and cockpit, engine transmission, aft electrical and radio compartment, and aft tail boom section, with and without gunfire. The acceleration amplitudes are compared with the MIL-STD-810B test curve, but no consideration is given to fatigue test criteria.

These data points repeat those given under the discussion of the entire helicopter plots, but these plots show the zones within the helicopter where the higher levels were measured.

In the frequency range of 200 to 5000 Hz, acceleration amplitudes are below 2g in the nose and cockpit section of the helicopter without gunfire (Figure 24). In all zones during gunfire, and in the aft tail boom section without gunfire, acceleration amplitudes generally approach or exceed 5g in the frequency range of 500 to 5000 Hz. Amplitudes near 25g are experienced in the aft tail boom section without gunfire at 1250 Hz.

Comparison of piezoelectric accelerometer vibration amplitudes without gunfire in the four zones, Figures 24, 26, 28, and 30, show maximum levels of 2g, 5g, 4g, and 25g respectively. This is not surprising, since Figures 26, 28, and 30 present the data nearer the engine, transmission, and tail rotor sources of excitation.

Examination of piezoelectric accelerometer zone plots (Figures 24-31) shows that the increase in vibration due to gunfire is most pronounced in the front quarter (forward of the guns), and that gunfire effects decrease toward the rear of the helicopter. Maximum levels in the tail boom section without gunfire (Figure 30) actually are greater than those during gunfire (Figure 31). The reason for this is that the gunfire-induced vibration is greatly attenuated in the tail boom section because of its distance from the guns, and vibration levels during some of the variety of non-gunfire flight conditions exceed those due to the combined effects of gunfire and the normal helicopter vibration during the gunfire maneuver.

Figure 32-39 are PSD plots for the helicopter zones. They are not discussed here, but are included for the reasons stated in Section III C.

E. GROUP PLOTS FOR SPECIFIC TRANSDUCER LOCATIONS

Each of the acceleration group plots (Figures 40-109) presents the

vibration data for clusters of either two or three piezoelectric or low frequency accelerometers oriented to sense vibration along the major helicopter axes. Group plots are included for all flight conditions without gunfire, and with gunfire. Each non-gunfire plot is followed by the gunfire plot for convenience in comparing non-gunfire with gunfire vibration. For example, Figure 40 is a non-gunfire plot and Figure 41 is the gunfire plot for the same location.

Finding a vibration plot for a particular location by referring to the List of Illustrations is rather tedious because of the large number of figures. The following alternative procedure is suggested:

1. Refer to Figure 2, 3, or 4 to obtain a drawing number for the location of interest. Figure 2, 3, and 4 illustrate locations of piezoelectric accelerometers, low frequency accelerometers, and microphones, respectively.
2. Refer to Table II to obtain the first transducer identification number (PUID) for this location. Selection of the first transducer number listed for each location is necessary because all of the data for a group of transducers are coded under the first listed number.
3. Starting with Figure 40, turn through the figures until a pickup identification number is found in the upper-left corner of the figure that corresponds to the transducer identification number from Table II.

The following example illustrates this procedure: Assume it is desired to find vibration plots for piezoelectric accelerometers located in the cockpit. First refer to Figure 2 and select drawing location 10, Pilot Pedestal, Left Side. From Table II, first page, transducer numbers 28, 29, and 30 correspond to drawing number 10. The first number of the group (28) is the PUID in the upper-left corner of Figures 58 and 59, which are for group plots for the Pilot's Pedestal, Left Side location without, and with gunfire, respectively. There are also two PSD plots for this location. These may be located by turning through PSD group plots (Figures 110 and 179) until PUID 28 is found on Figures 128 and 129.

In the preceding discussions of zone plots and plots for the entire helicopter, data points that exceeded the MIL-STD-810B test curve in the frequency range of 5 to 500 Hz were noted. The group plots also were reviewed to determine specific locations where the test curve was exceeded. Figure numbers and locations where the test curve is exceeded by data in the group plots are listed as follows:

1. Figure 41, gunner's instrument panel, left side, Station 60, with gunfire, 6g at 250 Hz.
2. Figure 43, gunner's pedestal, left side, Station 65, with gunfire, 9g, 6g, and 9g at 300 Hz, 400 Hz and 500 Hz, respectively.
3. Figure 45, gunner's pedestal, right side, Station 77, with gunfire, 9g at 200 Hz.
4. Figure 51, turret interface, Station 69, with gunfire, 9g at 250 Hz.
5. Figure 59, pilot's pedestal, left side, Station 122, with gunfire, 6g and 8g at 200 Hz and 400 Hz, respectively.
6. Figure 61, pilot's instrument compartment, left side, Station 122, with gunfire, 6g and 11g at 125 Hz and 200 Hz, respectively.
7. Figure 75, right wing top inboard, Station 186, with gunfire, 5.5g at 500 Hz.
8. Figure 76, UHF-VHF antenna compartment, Station 179, without gunfire, 5.5g at 500 Hz.
9. Figure 93, tail boom near 45° gear box, Station 470, with gunfire, 10g at 180 Hz.
10. Figure 94, tail boom near 90° gear box, Station 520, without gunfire, 5.5g at 100 Hz.
11. Figure 95, tail boom near 90° gear box, Station 520, with gunfire, 5.5g at 210 Hz.
12. Figure 106, aft electrical compartment near AN/ASN-43 gyro compass, Station 284, without gunfire, 0.8g at 10 Hz.
13. Figure 107, aft electrical compartment near AN/ASN-43 gyro compass, Station 284, with gunfire, 1g at 10 Hz.
14. Figure 108, tail boom near 90° gear box, Station 524, without gunfire, 1g at 10 Hz.
15. Figure 109, tail boom near 90° gear box, Station 524, with gunfire, 3.5g at 10 Hz.

Figure numbers and locations where 5g acceleration is exceeded in the frequency range of 500 to 6.4K Hz are as follows:

1. Figure 43, gunner's pedestal, left side, Station 65, with gunfire, 7g and 6g at 630 and 800 Hz, respectively.
2. Figure 51, XM-28 turret interface, Station 69, with gunfire, 6.5g, 6.5g, 10g and 7g at 630 Hz, 1200 Hz, 3200 Hz, and 6300 Hz, respectively.
3. Figure 73, right wing, top outboard, Station 191, with gunfire, 7g at 800 Hz.
4. Figure 75, right wing, top inboard, Station 186, with gunfire, 5.5g and 5.5g at 500 and 630, respectively.
5. Figure 76, UHF-VHF antenna compartment, Station 179, without gunfire, 5.5g at 500 Hz.
6. Figure 81, aft electronics compartment near AN/ARN-83, direction finder, Station 279, with gunfire, 6g at 1000 Hz.
7. Figure 83, aft electrical compartment near AN/ASN-43, gyro compass, Station 291, with gunfire, 10.5g at 2000 Hz.
8. Figure 87, tail boom, Station 400, with gunfire, 9g and 10g at 1250 and 6300 Hz, respectively.
9. Figure 92, tail boom near 45° gear box, Station 470, without gunfire, 11g, 25g and 22g at 500 Hz, 2000 Hz, and 4000 Hz, respectively.
10. Figure 93, tail boom near 45° gear box, Station 470, with gunfire, 8g and 9g at 2000 Hz and 4000 Hz, respectively.
11. Figure 94, tail boom near 90° gear box, Station 520, without gunfire, 11g, 11g, 14g, 19g and 14g at 1000 Hz, 1250 Hz, 2000 Hz, 4000 Hz, and 5000 Hz, respectively.
12. Figure 95, tail boom near 90° gear box, Station 520, with gunfire, 7g, 8g and 10.5g at 100 Hz, 1250 Hz, and 2000 Hz, respectively.

Low frequency vibration levels measured on the cabin floor are illustrated in Figures 98-99, and 102-105. They show that the maximum levels measured at this location did exceed 0.02 inch double amplitude or 0.5g below 160 Hz. The data from Figure 98 (without gunfire) were compared with MIL-H-8501A, Reference 2, Para. 3.7.1 for personnel stations in helicopters. Three curves taken from Para. 3.7.1 of this

specification are superimposed on the measured data. The data does exceed the curve for the speed range of "cruise velocity to limit velocity," the curve for transition, and the 0.15g curve for "30 knots rearward to cruise velocity" over the frequency range of 8 Hz to 100 Hz. Figure numbers and locations where MIL-H-8501A, para. 3.7.1(b) and (c), is exceeded in the frequency range of 5 to 160 Hz are as follows:

1. Figure 98, gunner's floor, Station 68, without gunfire, 0.5g, 0.3g, 0.25g, 0.55g, 0.6g, 1.1g at 10 Hz, 25 Hz, 31.5 Hz, 40 Hz, 50 Hz and 63 Hz, respectively.
2. Figure 99, gunner's floor, Station 68, with gunfire, 0.4g, 0.35g, 0.44g, 0.55g, 0.4g, 0.55g, 0.8g, and 0.7g at 10 Hz, 20 Hz, 25 Hz, 31.5 Hz, 40 Hz, 50 Hz, 63 Hz, and 80 Hz, respectively.
3. Figure 102, pilot's floor, Station 134, without gunfire, 0.25g, 0.27g, 0.25g, and 0.45g at 10 Hz, 31.5 Hz, 40 Hz, and 50 Hz, respectively.
4. Figure 103, pilot's floor, left side, Station 134, with gunfire, 0.27g, 0.3g, 0.3g, 0.27g, 0.27g and 0.22g at 10 Hz, 16 Hz, 20 Hz, 31.5 Hz, 63 Hz, and 80 Hz, respectively.
5. Figure 104, pilot's floor, right side, Station 134, without gunfire, 0.3g, 0.25g, 0.27g, 0.3g, 0.63g, 0.27g, 0.6g, and 0.25g at 10 Hz, 16 Hz, 20 Hz, 25 Hz, 31.5 Hz, 40 Hz, 50 Hz, and 63 Hz, respectively.
6. Figure 105, pilot's floor, right side, Station 134, with gunfire, 0.22g, 0.32g, 0.3g, 0.25g, 0.4g, 0.3g, 0.25g, and 0.22g at 10 Hz, 20 Hz, 25 Hz, 31.5 Hz, 40 Hz, 50 Hz, 63 Hz, and 80 Hz respectively.

Inspection of the piezoelectric accelerometer group plots for the cabin floor showed that with and without gunfire in the frequency range of 100 to 5000 Hz, the measured acceleration amplitudes did not exceed the test curve requirements of para. 3.7.1 of MIL-H-8501A.

For most locations forward of the guns, acceleration amplitudes were considerably higher during gunfire. At locations aft of the guns the acceleration levels are not much greater during gunfire than without gunfire.

Figures 110-179 are PSD group plots. These figures are not discussed here, but are included for the reasons stated in Section III C.

F. SOUND PRESSURE LEVELS

Sound pressure level (SPL) plots for internal and external helicopter locations during flight conditions without gunfire and during gunfire are shown in Figure 180-203. Levels measured in the cabin area without gunfire were compared with the requirements of MIL-S-008806B (USAF), Reference 3, Figure 2, Curve F. Figure 2 applies to crew and passenger compartments when standard-issue crew-member headgear is worn. Curve F specifies the maximum SPL's allowed for 30 minutes of cumulative mission time. The specification requirements are given for octave bands, but the data in this report are presented in one-third octave bands. It was necessary to reduce the specification levels by 5 dB to obtain equivalent one-third octave band levels for making direct comparison with plotted data. This reduction is conservative, since discrete components in the sound spectra usually result in octave band levels that are less than 5 dB greater than the one-third octave band levels. The reduced specification levels are superimposed on Figures 180 and 182 for the gunner's helmet and pilot's helmet, respectively. It is shown in these figures that the measured sound levels exceed those permitted by curve F of this specification by 16 dB at 31.5 Hz and by 5 dB at 40 and 50 Hz. In other octave bands, the levels are within specification requirements.

The total gunfire time per mission is limited to a maximum of 45 seconds by the 1500-round ammunition supply. Based on two gunfire missions per day, the maximum exposure of a crew member to gunfire is 1-1/2 minutes per day. Since MIL-S-008806B does not contain criteria for exposure durations less than 15 minutes, the 1-1/2 minute damage risk contour was utilized from a report entitled, "Hazardous Exposure to Intermittent and Steady State Noise." This report was prepared by Working Group 46 of the National Academy of Science, National Research Council Committee on Hearing, Bioacoustics, and Biomechanics (CHABA).

The report was published in the Journal of Acoustical Society of America, Reference 4. The phrase "damage risk contour" refers to a curve showing relation between SPL, band center frequency, and duration of exposure that will provide acceptable damage risk to hearing. This risk is considered acceptable if it produces, on the average, a permanent sound-induced hearing loss in people, after 10 years or more of near daily exposure, of no more than 10 dB at 1000 Hz, 15 dB at 2000 Hz, and 20 dB at 3000 Hz or above.

The SPL's measured in the cabin area during gunfire are shown in Figures 181 and 183. The 1-1/2 minute damage risk contour taken from Reference 4 is superimposed on Figure 181 for the gunner's helmet. It is shown that the measured SPL's at the gunner's helmet in the 400 Hz 1/3 octave band lies on the 1-1/2 minute contour curve without ear protection, but that the helmet with ear cups provides ample ear protection during gunfire. The helmet with ear cups also provides ample protection at the pilot's helmet as shown in Figure 183.

Figures 184-187 show SPL's measured in compartments where equipment is mounted. One-third octave levels, with and without gunfire, in these areas are below 120 dB and overall levels are below 130 dB. According to MIL-STD-810B, qualification tests should not be required for equipment installed where overall levels are below 130 dB.

Figures 188 to 203 show SPL's measured by microphones externally mounted. Overall levels without gunfire reached 153 dB at the top of the tail boom, Station 333, and with gunfire up to 156 dB was attained at the top of the tail boom, Station 458. Therefore, acoustic tests on equipment internally installed should not be required for simulating the non-gunfire or gunfire environment, but acoustic tests would be appropriate on acoustically sensitive equipment for simulating both non-gunfire and gunfire for externally mounted equipment.

SECTION IV

CONCLUSIONS

In frequency bands below 400 Hz amplitude, probability density plots indicate that AH-1G helicopter vibration, without gunfire and during gunfire, is more nearly sinusoidal than random. In frequency bands above 400 Hz, the helicopter vibration is predominantly random.

Vibration levels both with and without gunfire on the AH-1G helicopter exceed the sinusoidal test curve for equipment designed for helicopters from MIL-STD-810B, Figure 514-1, Curve M, in the frequency range of 5 to 500 Hz.

Significant acceleration levels are encountered in the AH-1G helicopter in the frequency range of 500 to 5000 Hz, which is above the 500 Hz upper limit of the MIL-STD-810B test curve.

Gunfire-induced vibration at most locations near and forward of the gun muzzles is much higher than that encountered without gunfire.

Vibration levels measured on the cargo floor, with low frequency accelerometers, do exceed the maximum levels allowed by MIL-H-8501A, para. 3.7.1 for personnel stations in helicopters.

Since the vibration levels presented here are dependent on bandwidths used in analyzing the data, the bandwidths defined in Section IID should be considered in applying these levels to the development of test criteria.

Sound pressure levels with and without gunfire near the pilot's and gunner's helmets are below the maximum levels specified in MIL-S-008806B (USAF), Curve F, for personnel compartments where ear protection is used.

Based on the 1-1/2 minute damage risk contours prepared by Working Group 46 of the National Academy of Science, National Research Council Committee on Hearing, Bioacoustics, and Biomechanics, the sound pressure levels existing in the AH-1G helicopter during gunfire are below those that would cause permanent and significant hearing loss if personnel are equipped with standard issue helmets and ear cups.

SECTION V

RECOMMENDATIONS

Based on data contained in this report, and on other available data on helicopter vibration environments, it is recommended that tri-service action be expedited to update applicable military standards by:

1. Revising vibration test specifications for equipment mounted in helicopters by extending the upper frequency limit from 500 to 5000 Hz.
2. Synthesizing a vibration simulation procedure in which low frequency swept sinusoids are superimposed on random noise in the upper frequency region (above approximately 200 Hz).
3. Integrating into a similar procedure for vibration induced by gunfire.

TABLE II
PICKUP LOCATIONS AND DESCRIPTION - AH-1G

PUID	Pickup Type	Drawing Loc. No.	Direction	Location Description
1	Piezo	1	F&A	Gunner's Instrument Panel, Left Side, Sta. 60
2	Accel		Lat	
3			Vert	
4	Piezo	2	F&A	Gunner's Pedestal, Left Side, Sta. 65
5	Accel		Lat	
6			Vert	
7	Piezo	3	F&A	Gunner's Pedestal, Right Side, Sta. 77
8	Accel		Lat	
9			Vert	
10	Piezo	4	F&A	Gunner's Instrument Comp., Right Side, Sta. 73
11	Accel		Lat	
12			Vert	
13	Piezo	5	F&A	Gunner's Floor, Center, Sta. 66
14	Accel		Lat	
15			Vert	
16	Piezo	6	F&A	XM-28 Turret Interface, Sta. 69
17	Accel		Lat	
18			Vert	
19	Piezo	7	F&A	Pilot's Floor, Center, Sta. 134
20	Accel		Lat	
21			Vert	
22	Piezo	8	F&A	XM-28 Turret, Center, Sta. 77
23	Accel		Lat	
24			Vert	
25	Piezo	9	F&A	Pilot's Instrument Panel, Right Side, Sta. 115
26	Accel		Lat	
27			Vert	
28	Piezo	10	F&A	Pilot's Pedestal, Left Side, Sta. 122
29	Accel		Lat	
30			Vert	
31	Piezo	11	F&A	Pilot's Instrument Comp., Left Side, Sta. 122
32	Accel		Lat	
33			Vert	

TABLE II (Cont'd)

PUID	Pickup Type	Drawing Loc. No.	Direction	Location Description
34	Piezo	12	F&A	Pilot's Instrument Comp., Right Side, Sta. 130
35	Accel		Lat	
36			Vert	
37	Piezo	13	F&A	Pilot's Pedestal, Right Side, Sta. 136
38	Accel		Lat	
39			Vert	
40	Piezo	14	F&A	Main Transmission Mount, Left Front, Sta. 188
41	Accel		Lat	
42			Vert	
43	Piezo	15	F&A	Main Transmission Mount, Right Rear, Sta. 202
44	Accel		Lat	
45			Vert	
46	Piezo	16	F&A	Engine Mount, Left Side, Sta. 244
47	Accel		Lat	
48			Vert	
49	Piezo	17	F&A	Right Wing, Top Outboard, Sta. 191
50	Accel		Lat	
51			Vert	
52	Piezo	18	F&A	Right Wing, Top Inboard, Sta. 186
53	Accel		Lat	
54			Vert	
55	Piezo	19	F&A	UHF-VHF Antenna Comp., Sta. 179
56	Accel		Lat	
57			Vert	
58	Piezo	20	F&A	FM Antenna Comp., Sta. 238
59	Accel		Lat	
60			Vert	
61	Piezo	21	F&A	Aft Electrical Comp., near AN/ARN-83 Direction Finder, Sta. 279
62	Accel		Lat	
63			Vert	
64	Piezo	22	F&A	Aft Electrical Comp., near AN/ASN-43 Gyro Compass, Sta. 291
65	Accel		Lat	
66			Vert	
67	Piezo	23	F&A	Structure near AN/APX-72 Transponder, Sta. 330
68	Accel		Lat	
69			Vert	

TABLE II (Cont'd)

PUID	Pickup Type	Drawing Loc. No.	Direction	Location Description
70	Piezo	24	F&A	Tail Boom, Sta. 400
71	Accel		Lat	
72			Vert	
73	Piezo	25	F&A	Radio Compartment near AN/ARC-51 Transceiver, Sta. 346
74	Accel		Lat	
75			Vert	
76	Piezo	26	F&A	Radio Compartment near AN/ARC-134 Tranceiver, Sta. 364
77	Accel		Lat	
78			Vert	
79	Piezo	27	F&A	Tail Boom near 45° Gear Box, Sta. 470
80	Accel		Lat	
81			Vert	
82	Piezo	28	F&A	Tail Boom near 90° Gear Box, Sta. 520
83	Accel		Lat	
84			Vert	
85	Low Freq Accel	1	Vert	Gunner's Instr. Panel, Left Side, Sta. 60
86	Low Freq	2	Vert	Gunner's Floor, Sta. 68
87	Accel		Lat	
88	Low Freq	3	Vert	Pilot's Instr. Panel, Right Side, Sta. 115
89	Accel		Lat	
90	Low Freq Accel	4	Vert	Pilot's Floor, Left Side, Sta. 134
91	Low Freq	5	Lat	Pilot's Floor, Right Side, Sta. 134
92	Accel		Vert	
93	Low Freq	6	Vert	Aft Electrical Comp. near AN/ASN-43 Gyro Compass, Sta. 284
94	Accel		Lat	
95	Low Freq	7	Vert	Tail Boom near 90° Gear Box, Sta. 524
96	Accel		Lat	
97	Piezo Mike	1	Diaph Up	Canopy Top, Outside, Sta. 58
98	Piezo Mike	2	Diaph Up	Canopy Top, Outside, Sta. 103
99	Piezo Mike	3	Diaph Up	Tail Boom Top, Outside, Sta. 333

TABLE II (Cont'd)

PUID	Pickup Type	Drawing Loc. No.	Direction	Location Description
A1	Piezo Mike	4	Diaph Up	Tail Boom Top, Outside, Sta. 393
A2	Piezo Mike	5	Diaph Up	Tail Boom Top, Outside Sta. 458
A3	Piezo Mike	6	Diaph Down	Nose Bottom, Outside, Sta. 54
A4	Piezo Mike	7	Diaph Forward	Wing Right, Outside, Sta. 184
A5	Piezo Mike	8	Diaph Down	Below Aft Elec. Comp., Outside, Sta. 287
A6	Piezo Mike	9	Diaph Up	Aft Electrical Comp., Sta. 284
A7	Piezo Mike	10	Diaph Up	Radio Compartment, Sta. 390
A8	Piezo Mike	11	Diaph Forward	Gunner's Helmet, Sta. 90
A9	Piezo Mike	12	Diaph Forward	Pilot's Helmet, Sta. 140

TABLE III
FLIGHT CONDITIONS SELECTED FOR DATA REDUCTION - AH-1G

Condition	IAS (Knots)	Altitude (feet)	PUID's
Ground Runup, 220 rpm	0	0	ALL
Ground Runup, 330 rpm	0	0	ALL
Take-off (vertical) & Touch Down	0	0-200	ALL
Take-off, Normal Rated Power	50-90	0-600	ALL
Level Flight	20	500	ALL
Level Flight	60	500	ALL
Level Flight	100	500	ALL
Level Flight	140	500	ALL
Level Flight	150-180	500	ALL
Level Flight	20	5000	ALL
Level Flight	60	5000	ALL
Level Flight	100	5000	ALL
Level Flight	145	5000	ALL
Level Flight	20	10,000	ALL
Level Flight	60	10,000	ALL
Level Flight	100	10,000	ALL
Level Flight	125	10,000	ALL
Climb, Maximum	90	300-700	ALL
Climb, Maximum	60-100	4500-5500	ALL
Hover, in Ground Effects	0	10	ALL
Hover	0	600	ALL
Left Turn, 30°	115	500	ALL
Left Turn, 60°	120	500	ALL

TABLE III (Cont'd)

Condition	IAS (Knots)	Altitude (feet)	PUID's
Left Turn, 30°	115	10,000	ALL
Left Turn, 60°	100	10,000	ALL
Combat Approach, Spiral	150	5000-0	ALL
Auto Rotation	120	5000-0	ALL
Taxi	5-10	10	ALL
Gunfire, Wing Mounted Guns, 2000 rounds/min.	180	1000	ALL
Rocket Salvo, Inboard Pods	180	1000	61-72
Rocket Salvo, Outboard Pods	180	1000	73-84
Grenade Salvo, Straight Ahead	180	1000	ALL
Grenade Salvo, 90° rt and 45° down	180	1000	ALL
Grenade Salvo, 90° lft and 45° down	180	1000	13-24
Gunfire, Twin Turret Guns, Straight Ahead, 2000 rounds/min.	180	1000	ALL
Gunfire, Twin Miniguns in Turret Straight Ahead, 4000 rounds/min.	180	1000	ALL except 1-12
Gunfire, Twin Miniguns in Turret, 90° rt and 45° down, 2000 rounds/min.	180	1000	ALL
Gunfire, Twin Miniguns in Turret, 90° rt and 45° down, 4000 rounds/min.	180	1000	13-24
Gunfire, Twin Miniguns in Turret, 90° lft and 45° down, 2000 rounds/min.	180	1000	13-24
Gunfire, Twin Miniguns in Turret, 90° lft and 45° down, 4000 rounds/min.	180	1000	13-24

REFERENCES

1. "Military Standard Environmental Test Methods," MIL-STD-810B, Notice 1, October 1969.
2. "Helicopter Flying and Ground Handling Qualities; General Requirements for MIL-H-850A," November 1961.
3. "Military General Specification for Sound Pressure Levels in Aircraft," MIL-S-008806B, July 1970, (USAF).
4. "Journal of Acoustical Society of America," Vol. 39, No. 3, Pages 451-464, March 1966.

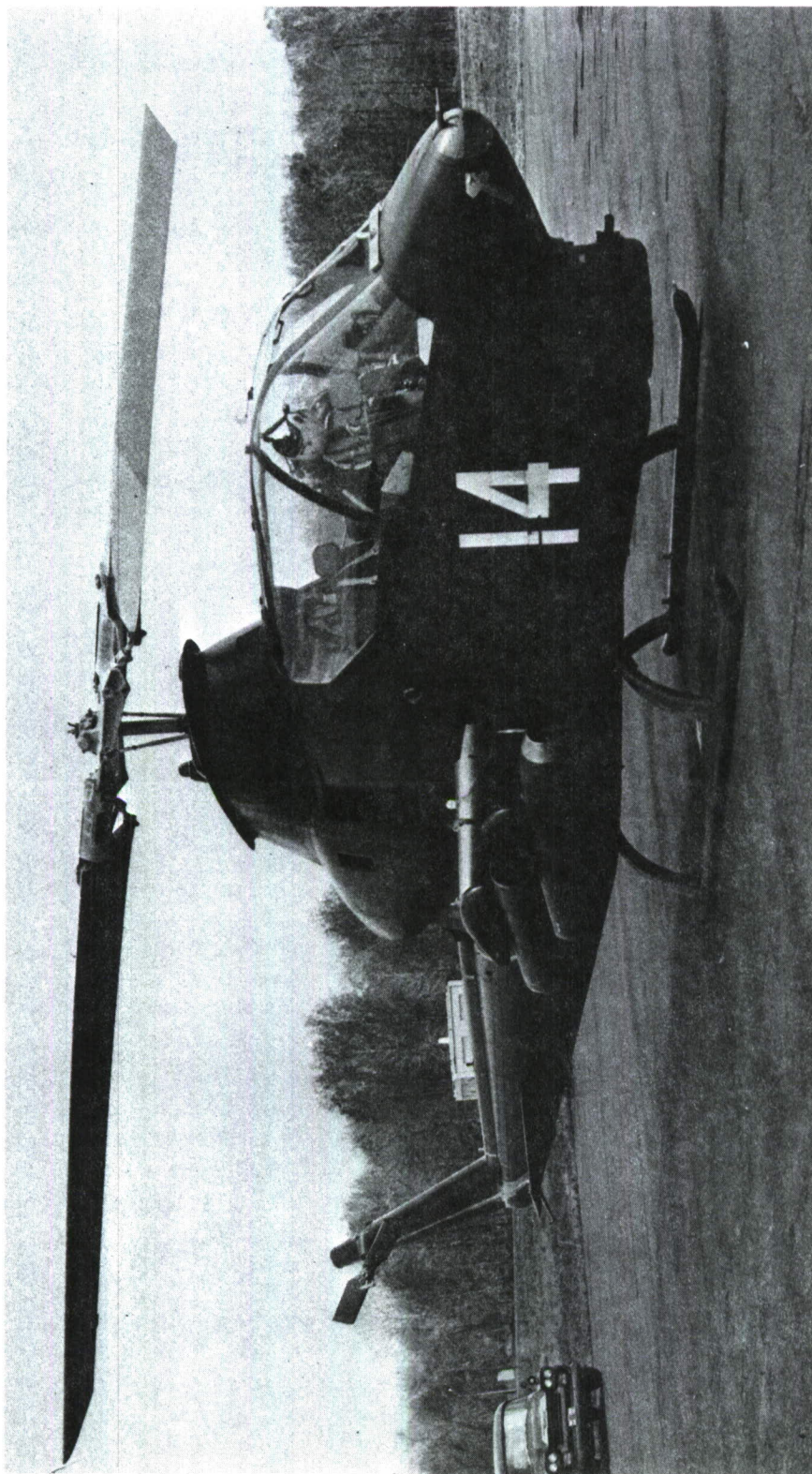


Figure 1. AH-1G Helicopter, S/N 67-15711 with Armament

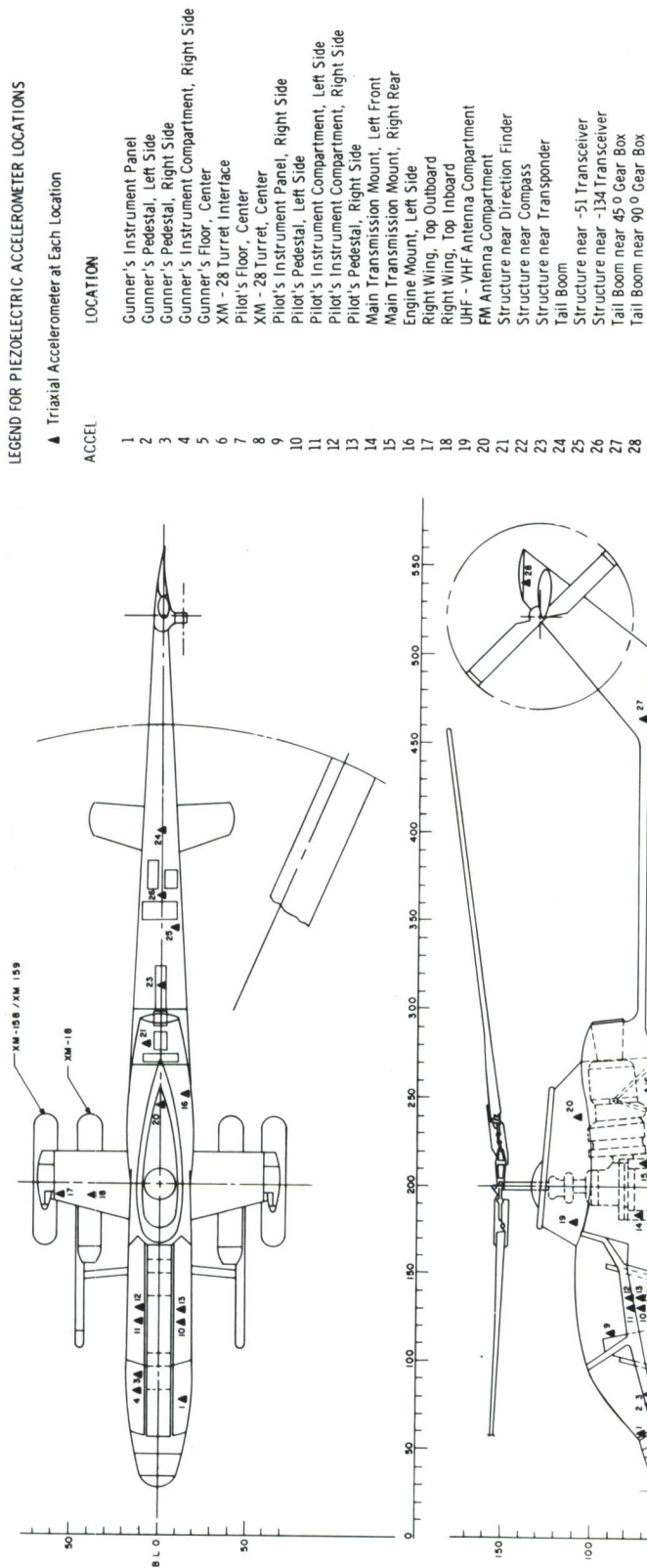


FIGURE 2. Piezoelectric Accelerometer Locations

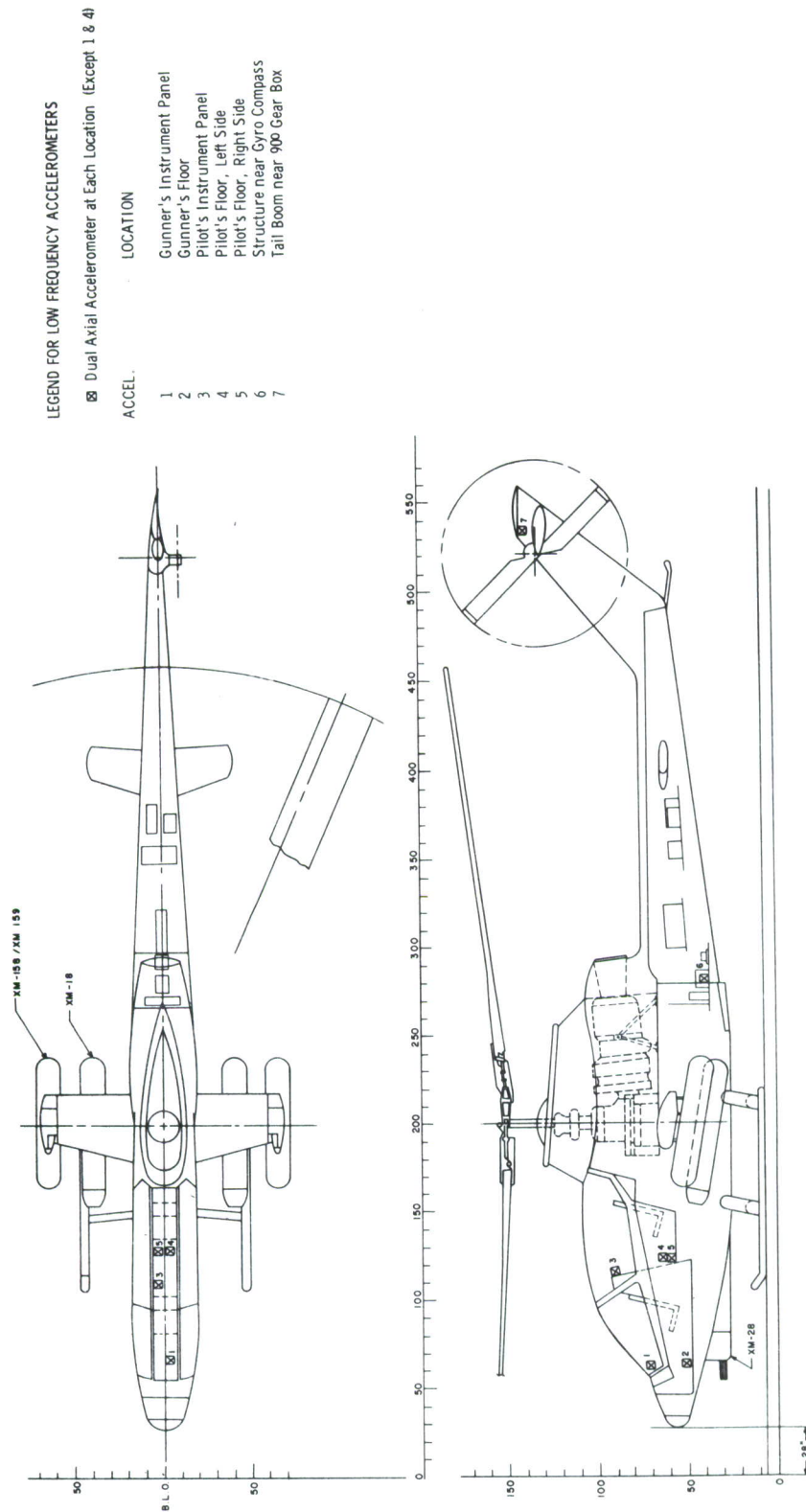


FIGURE 3. Low Frequency Accelerometer Locations

MICROPHONE	LOCATION
1	Canopy Top, Outside
2	Canopy Top, Outside
3	Tail Boom Top, Outside
4	Tail Boom Top, Outside
5	Tail Boom Top, Outside
6	Nose Bottom, Outside
7	Wing Right, Outside
8	Below Electronic Comp
9	Aft Electronic Comp
10	Radio Compartment
11	Gunner's Helmet
12	Pilot's Helmet

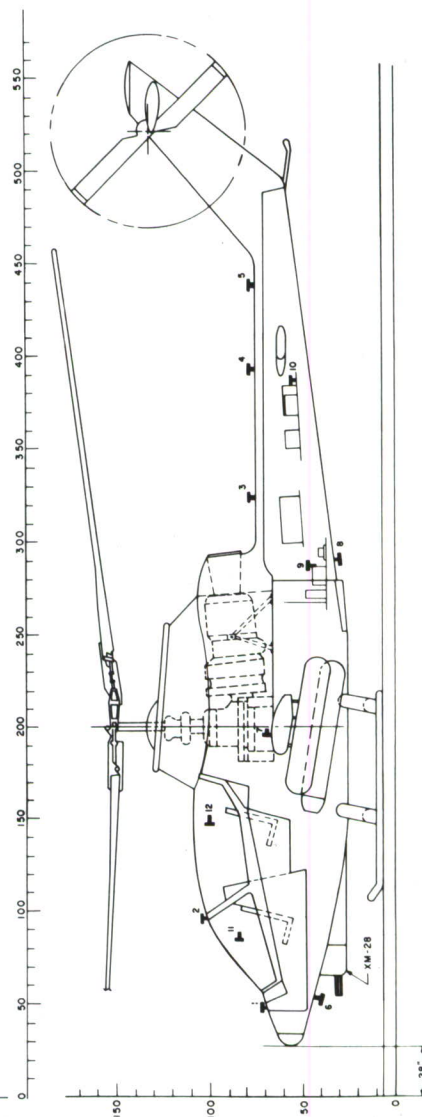


FIGURE 4. Microphone Locations

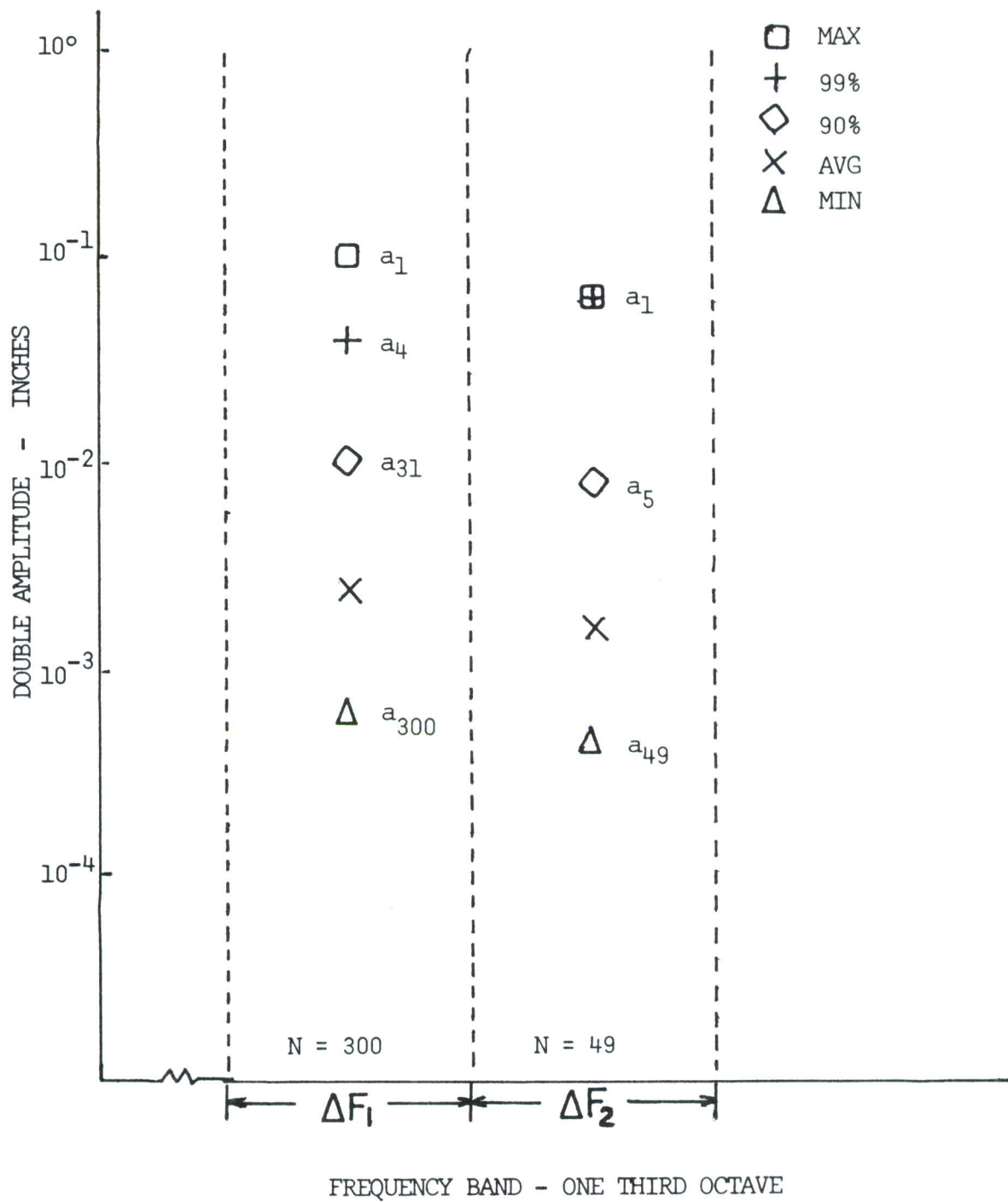


Figure 5. Percentile Plot Illustration

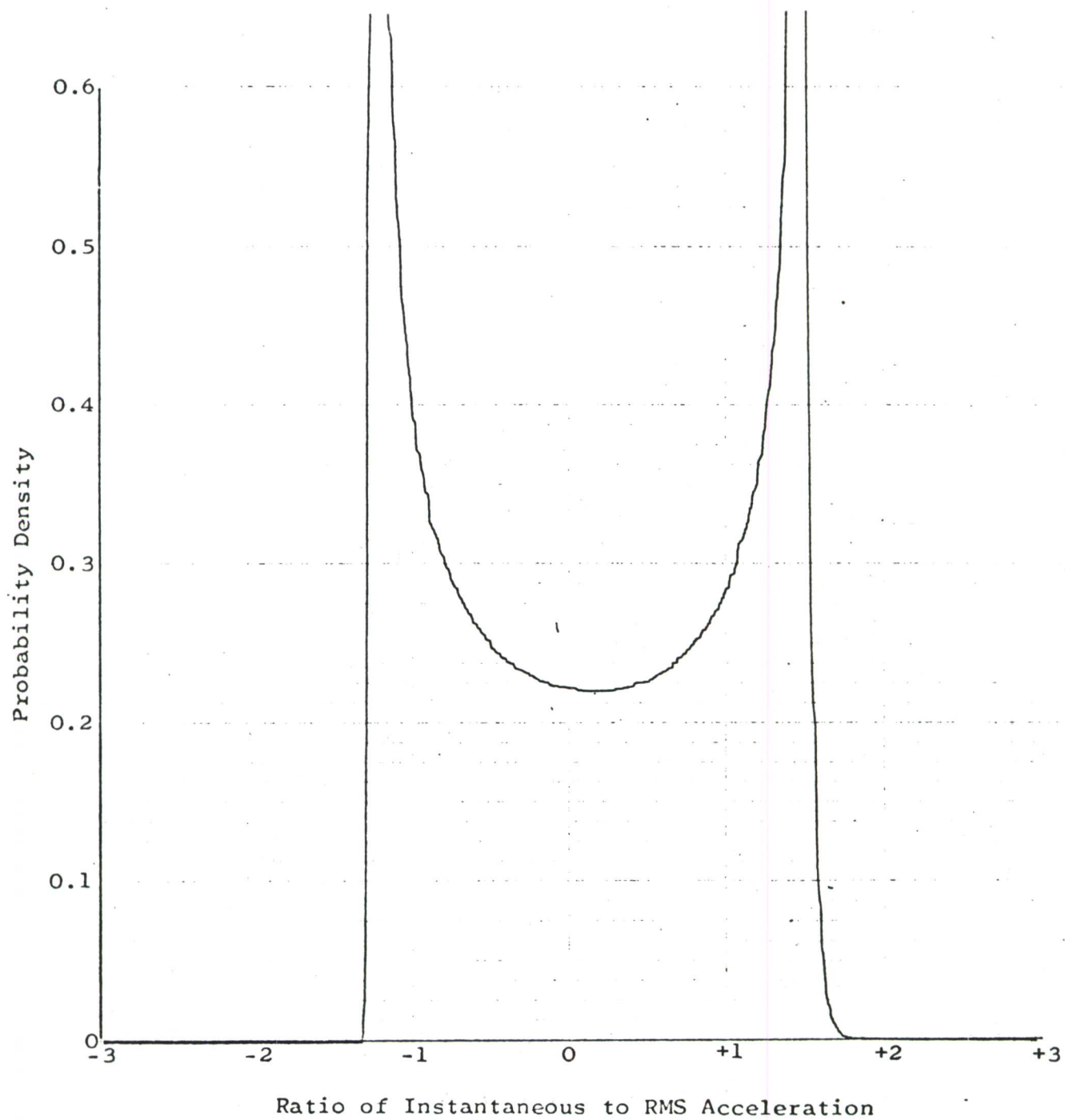


Figure 6. Sinusoidal Input

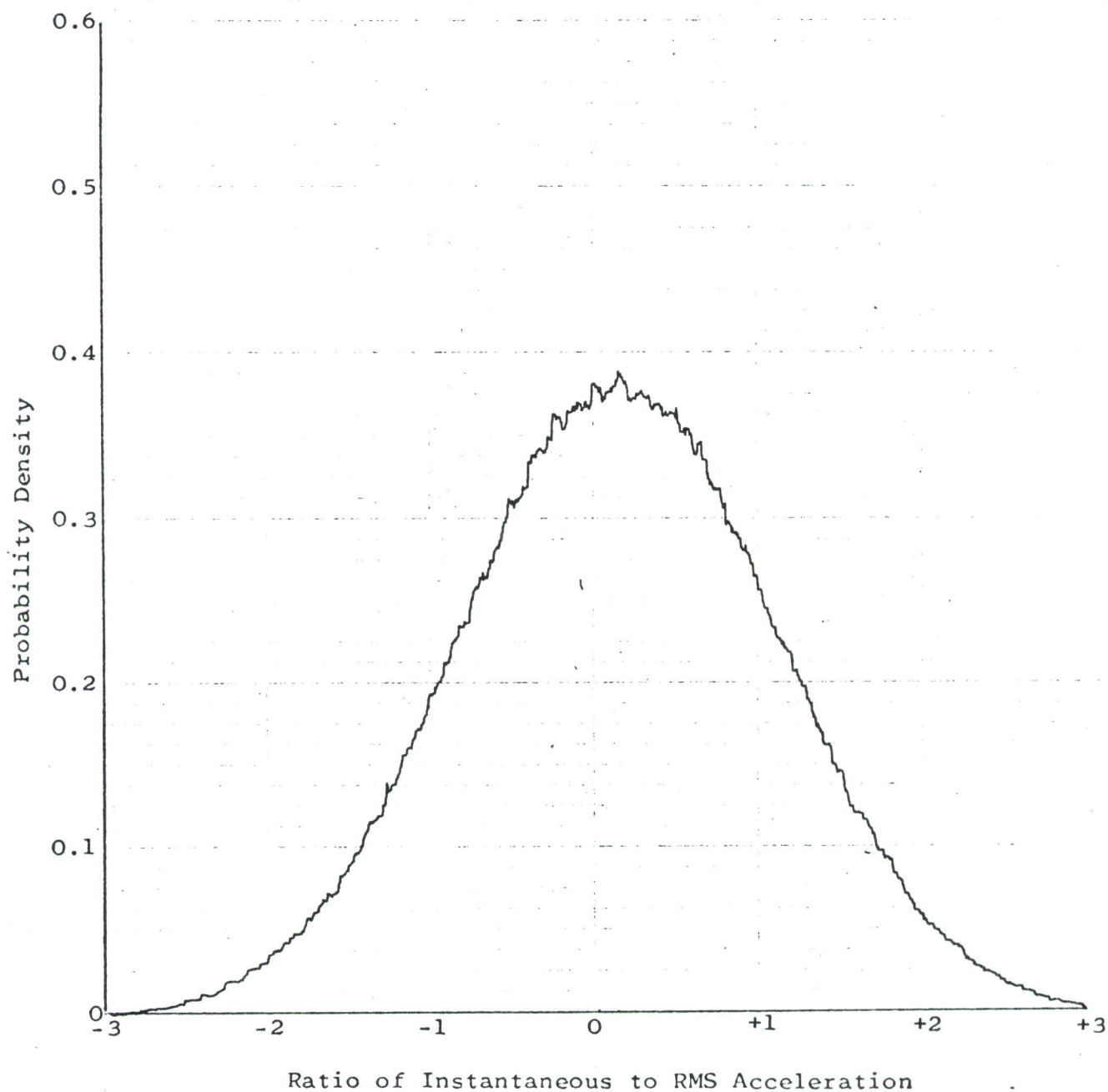


Figure 7. Random Gaussian Input

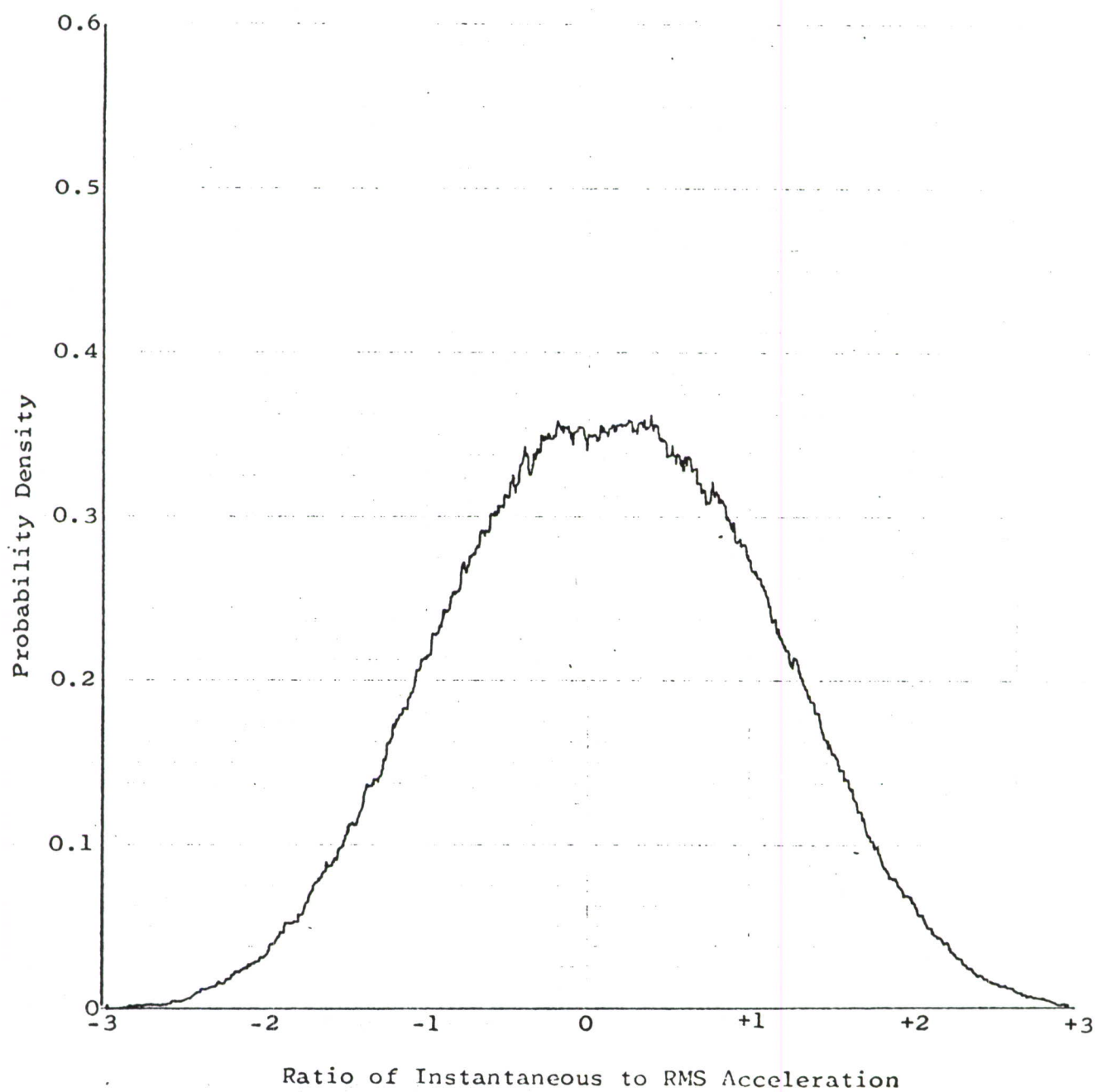


Figure 8. Ratio of Random to Sinusoidal Component of 1:1

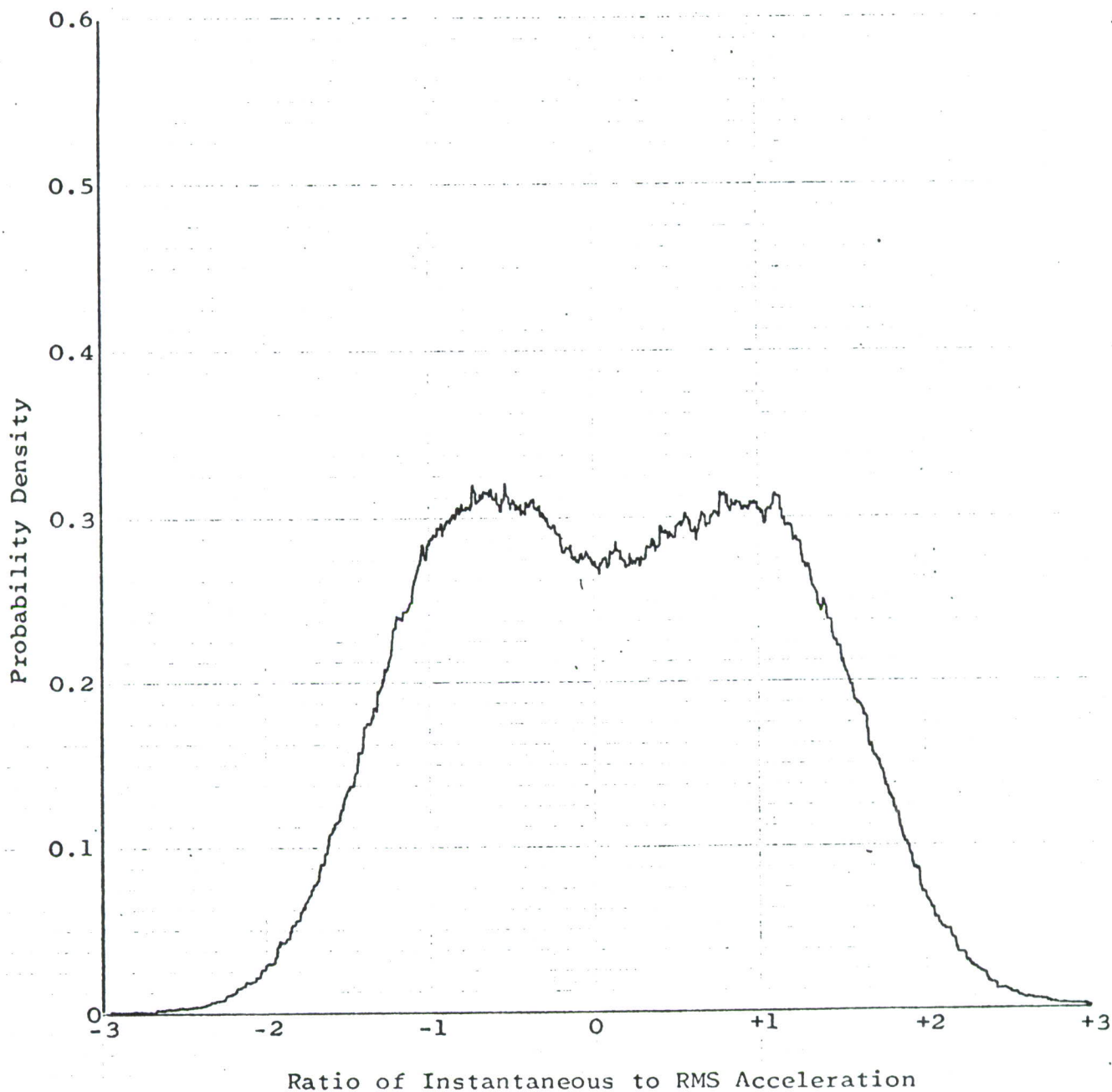


Figure 9. Ratio of Random to Sinusoidal Component of 1:2

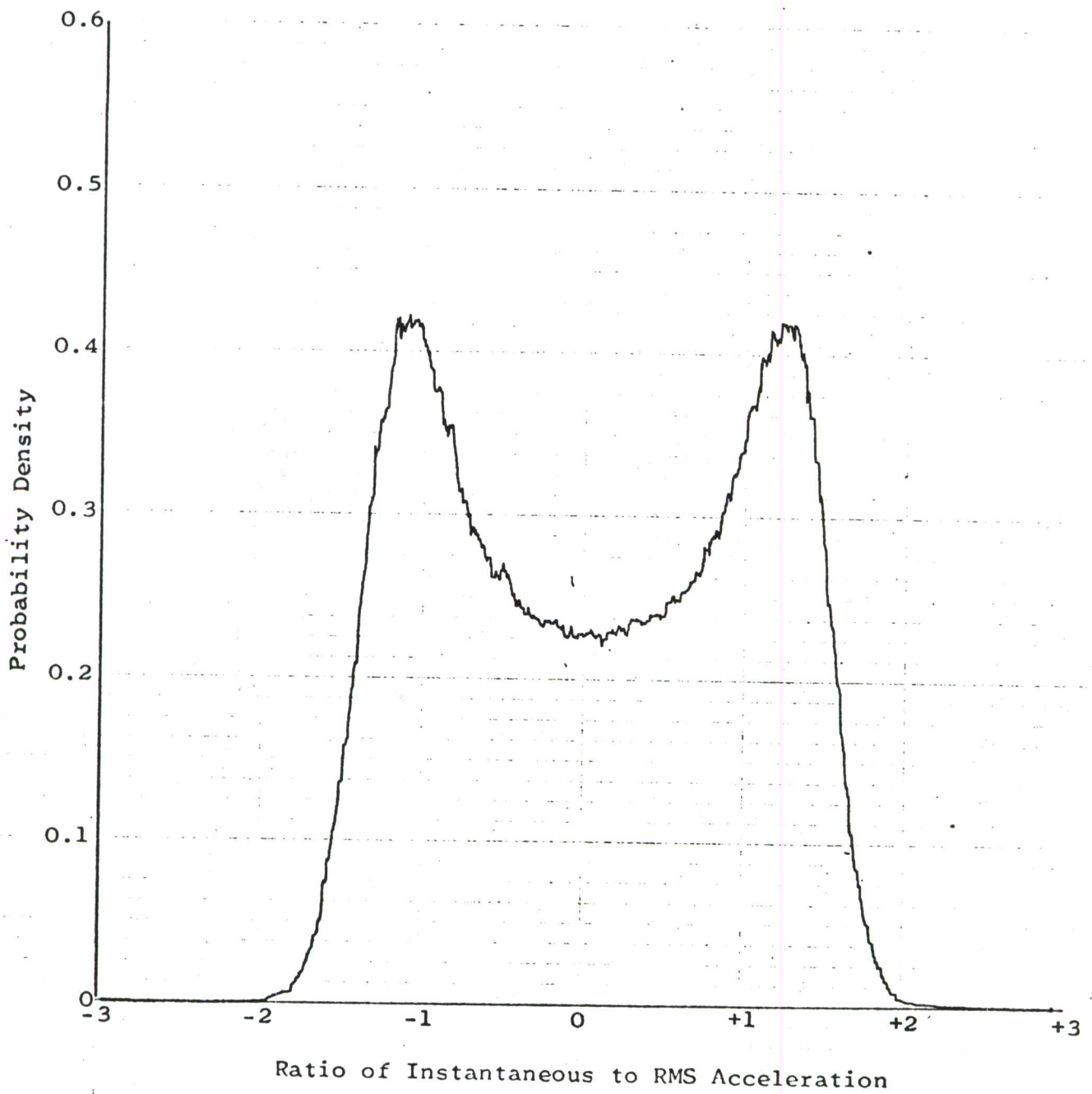


Figure 10. Ratio of Random to Sinusoidal Component of 1:5

Accelerometer Location: Pilot's Pedestal, Left Side, Sta. 122

Flight Condition: Level Flight, 500 Ft. Alt., 150 KIAS

Center Frequency: 42 Hz

Bandwidth: 5 Hz

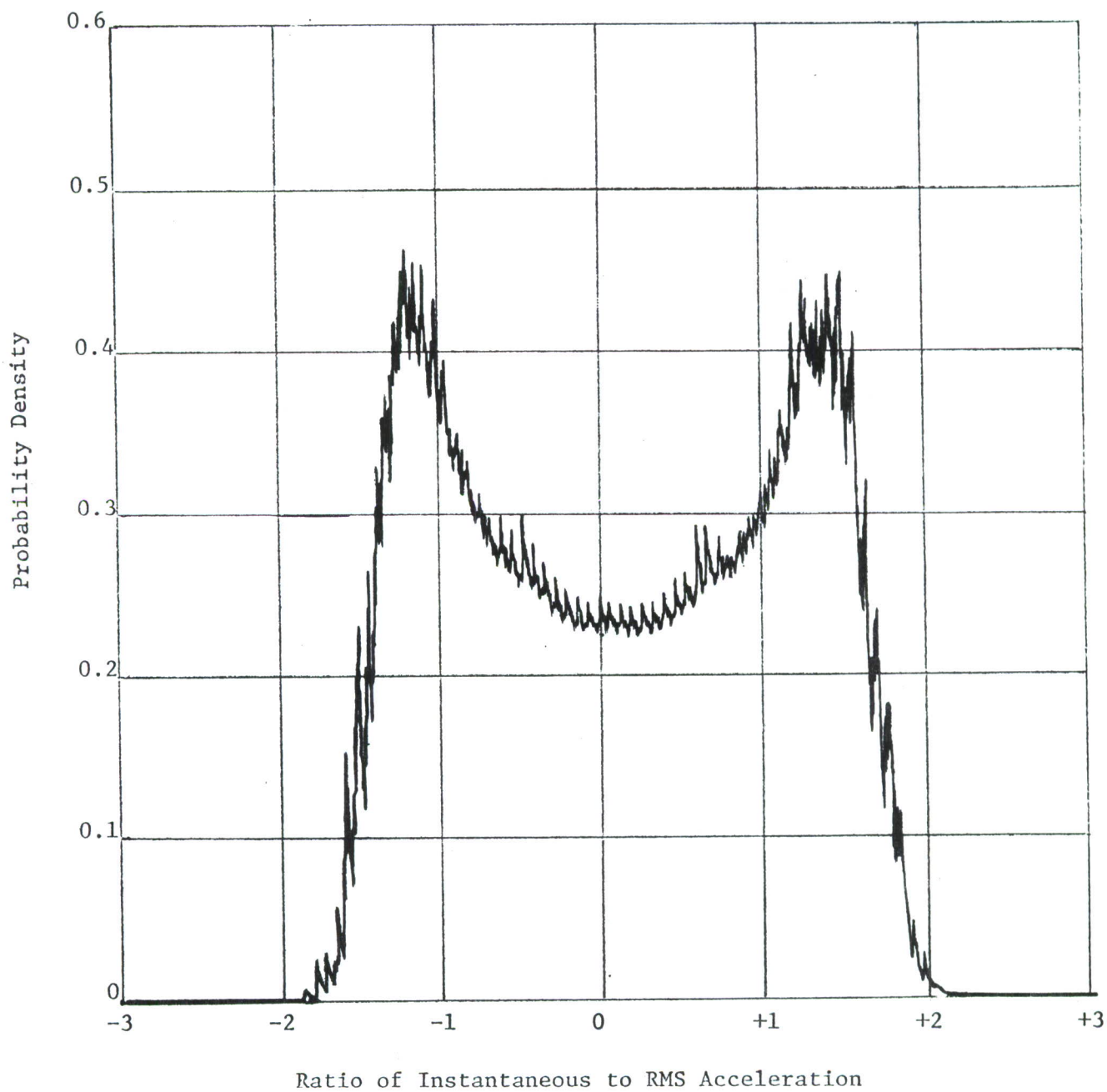


Figure 11. Acceleration APD, Level Flight, 42 Hz Center Frequency

Accelerometer Location: Pilot's Pedestal, Left Side, Sta. 122

Flight Condition: Level Flight, 500 Ft. Alt., 150 KIAS

Center Frequency: 204 Hz

Bandwidth: 10 Hz

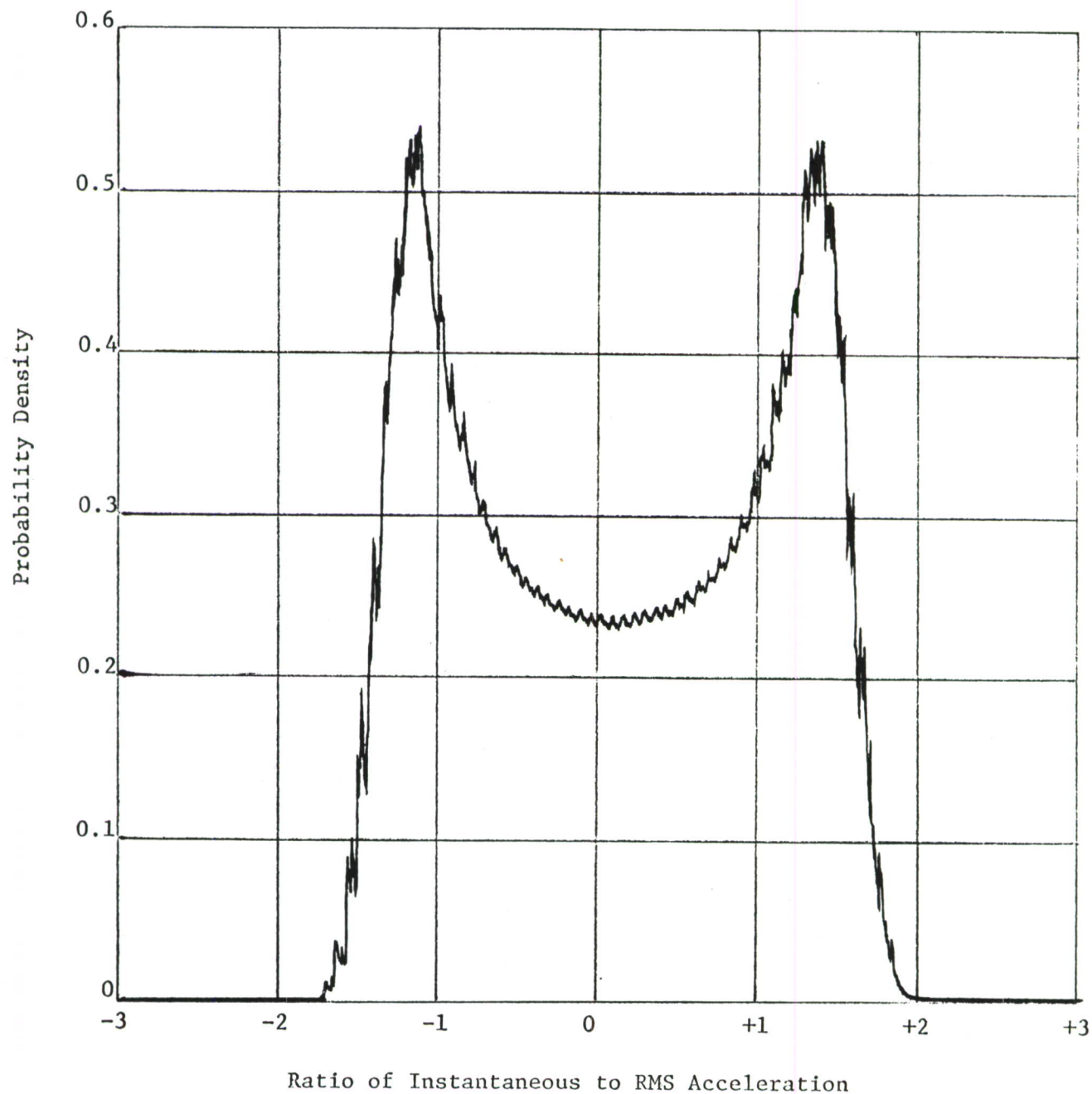


Figure 12. Acceleration APD, Level Flight, 204 Hz Center Frequency

Accelerometer Location: Pilot's Pedestal, Left Side, Sta. 122

Flight Condition: Level Flight, 500 Ft. Alt., 150 KIAS

Center Frequency: 412 Hz

Bandwidth: 20 Hz

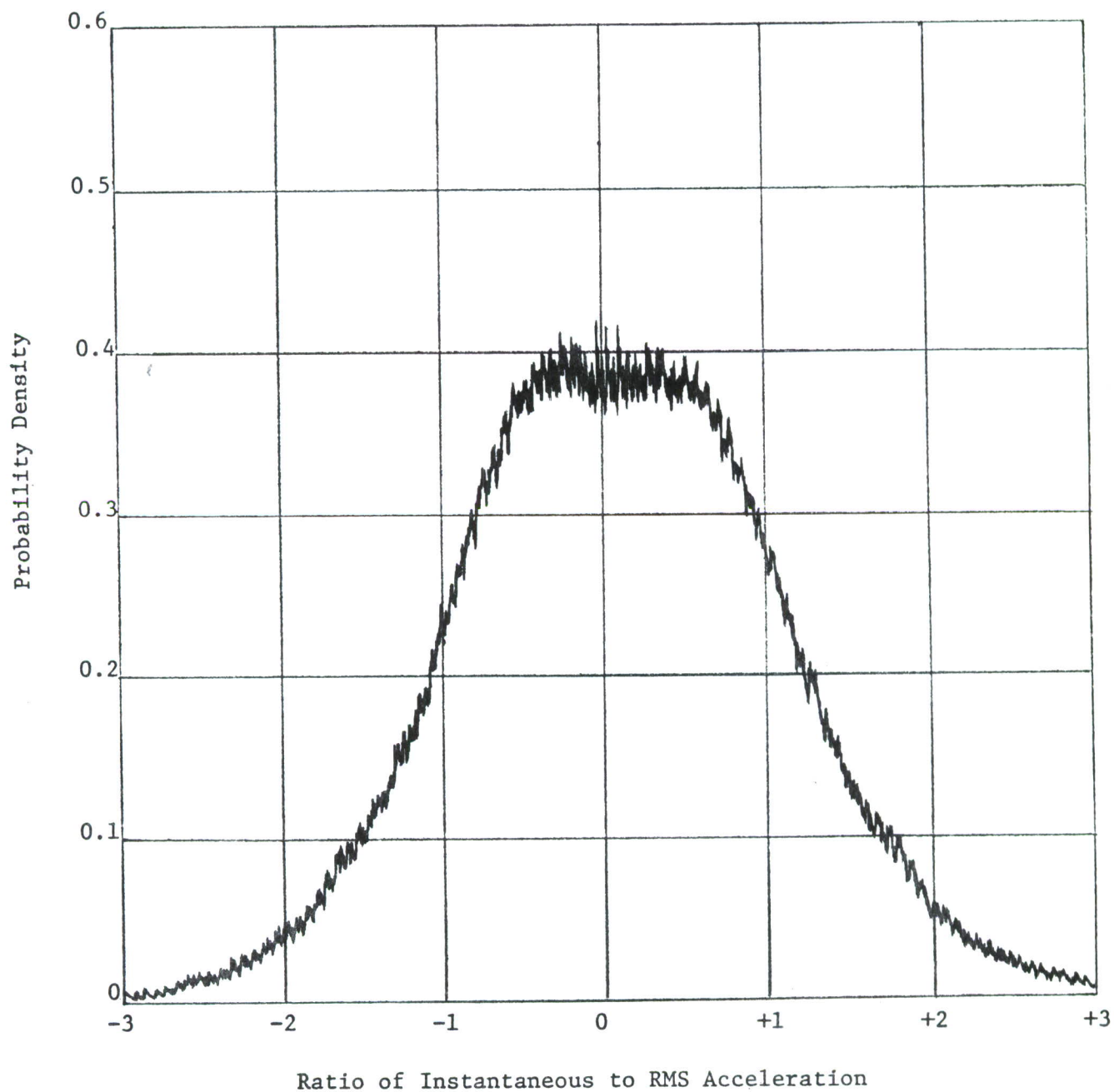


Figure 13. Acceleration APD, Level Flight, 412 Hz Center Frequency

Accelerometer Location: Pilot's Pedestal, Left Side, Sta. 122

Flight Condition: Gunfire, Nose Turret Guns, 4000 SPM

Center Frequency: 22 Hz

Bandwidth: 5 Hz

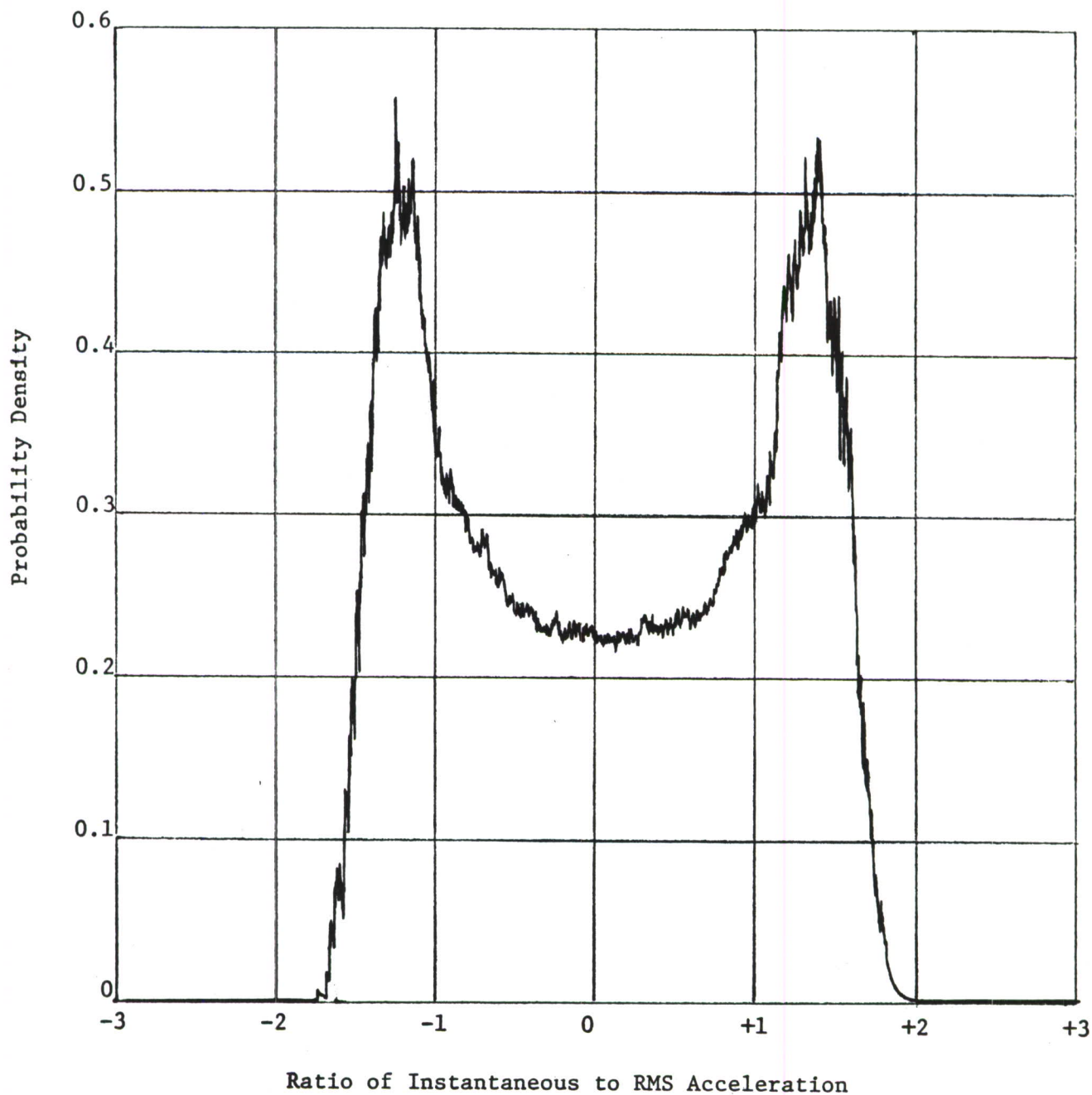


Figure 14. Acceleration APD, Gunfire, 4000 SPM, 22 Hz Center Frequency

Accelerometer Location: Pilot's Pedestal, Left Side, Sta. 122

Flight Condition: Gunfire, Nose Turret Guns, 4000 SPM

Center Frequency: 192 Hz

Bandwidth: 10 Hz

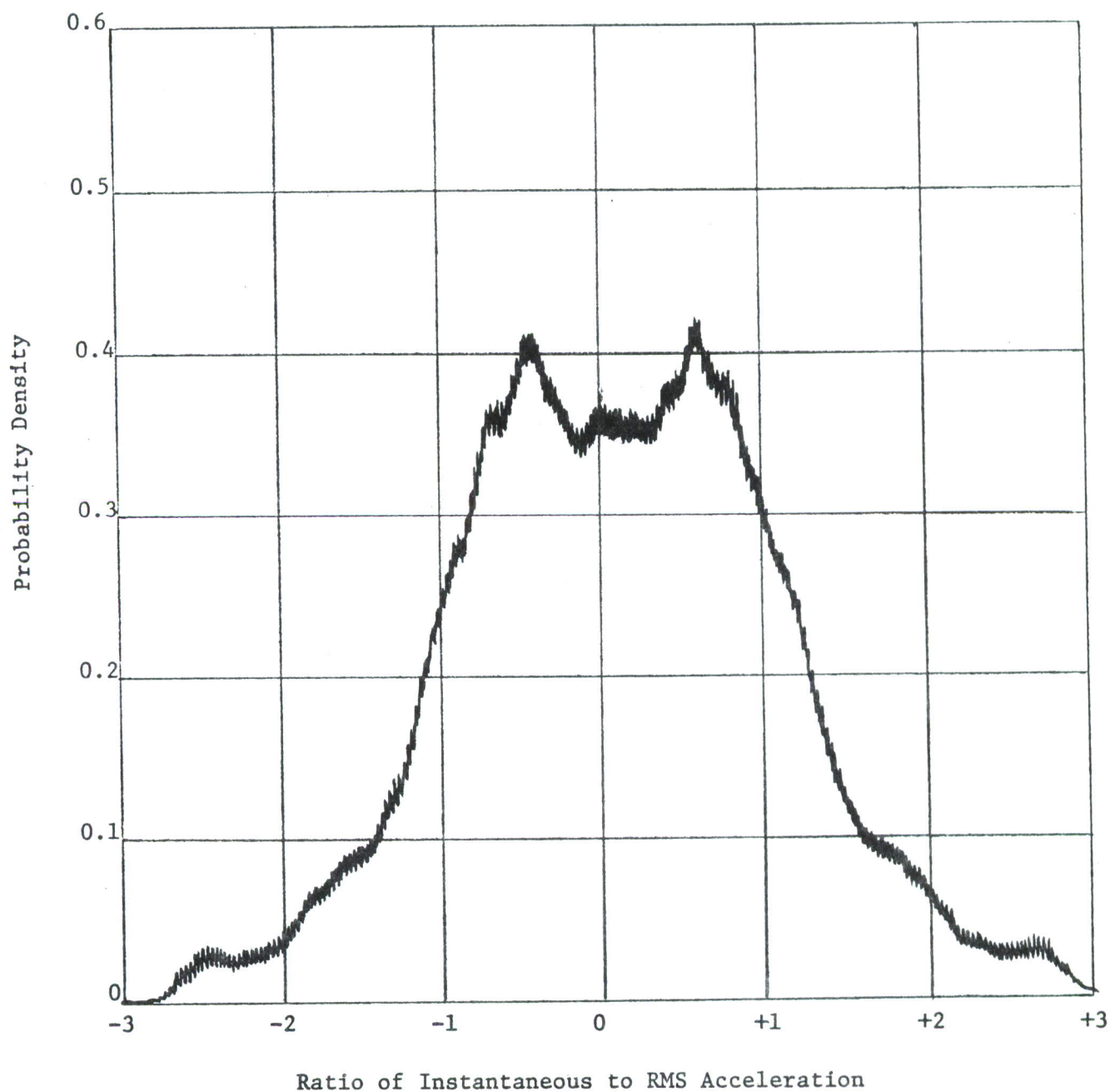


Figure 15. Acceleration APD, Gunfire, 4000 SPM, 192 Hz Center Frequency

Accelerometer Location: Pilot's Pedestal, Left Side, Sta. 122

Flight Condition: Gunfire, Nose Turret Guns, 4000 SPM

Center Frequency: 446 Hz

Bandwidth: 20 Hz

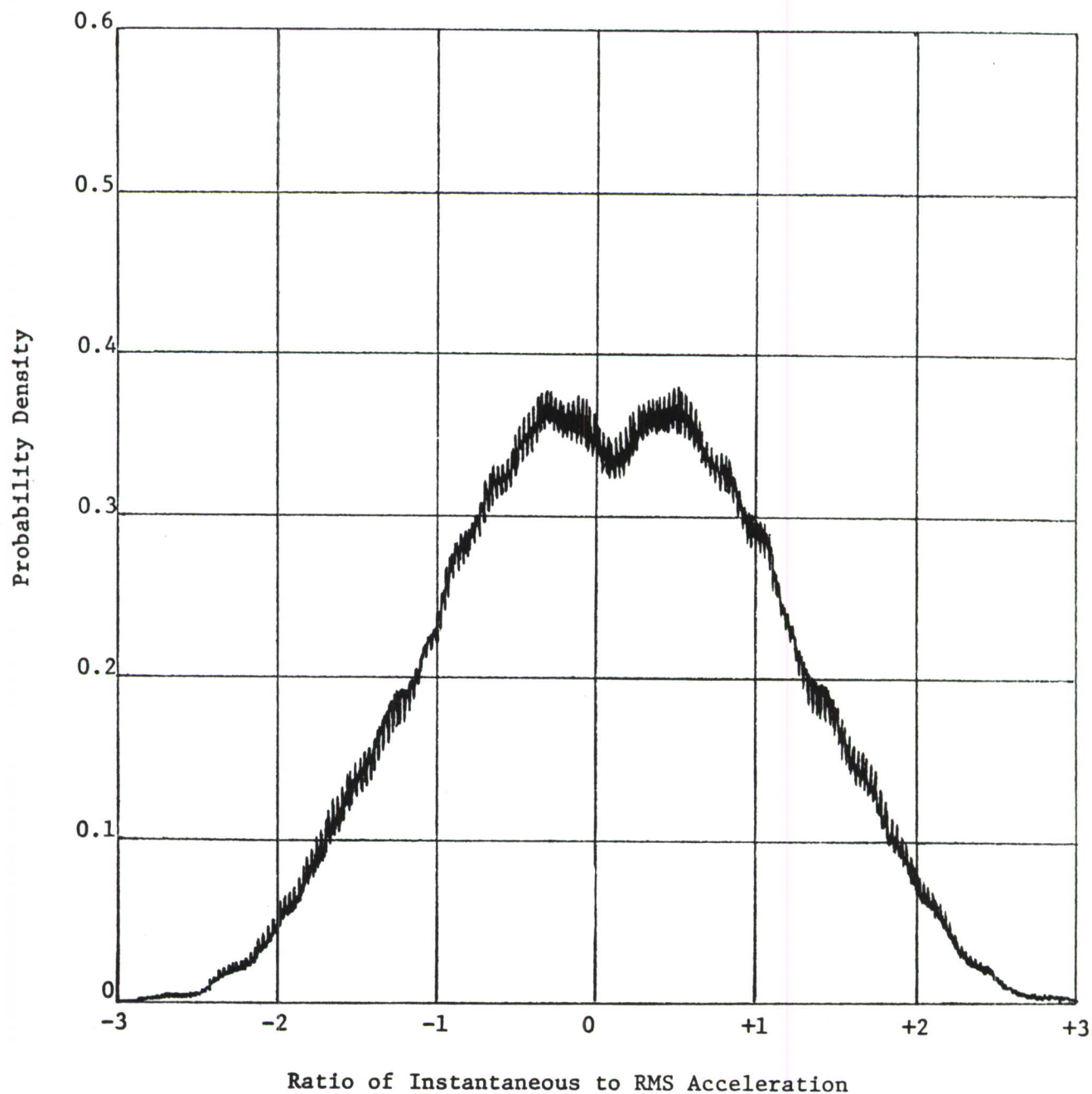


Figure 16. Acceleration APD, Gunfire, 4000 SPM, 446 Hz Center Frequency

Accelerometer Location: Pilot's Pedestal, Left Side, Sta. 122

Flight Condition: Rocket Salvo, Inboard Pylons, 6 SPS

Center Frequency: 105 Hz

Bandwidth: 10 Hz

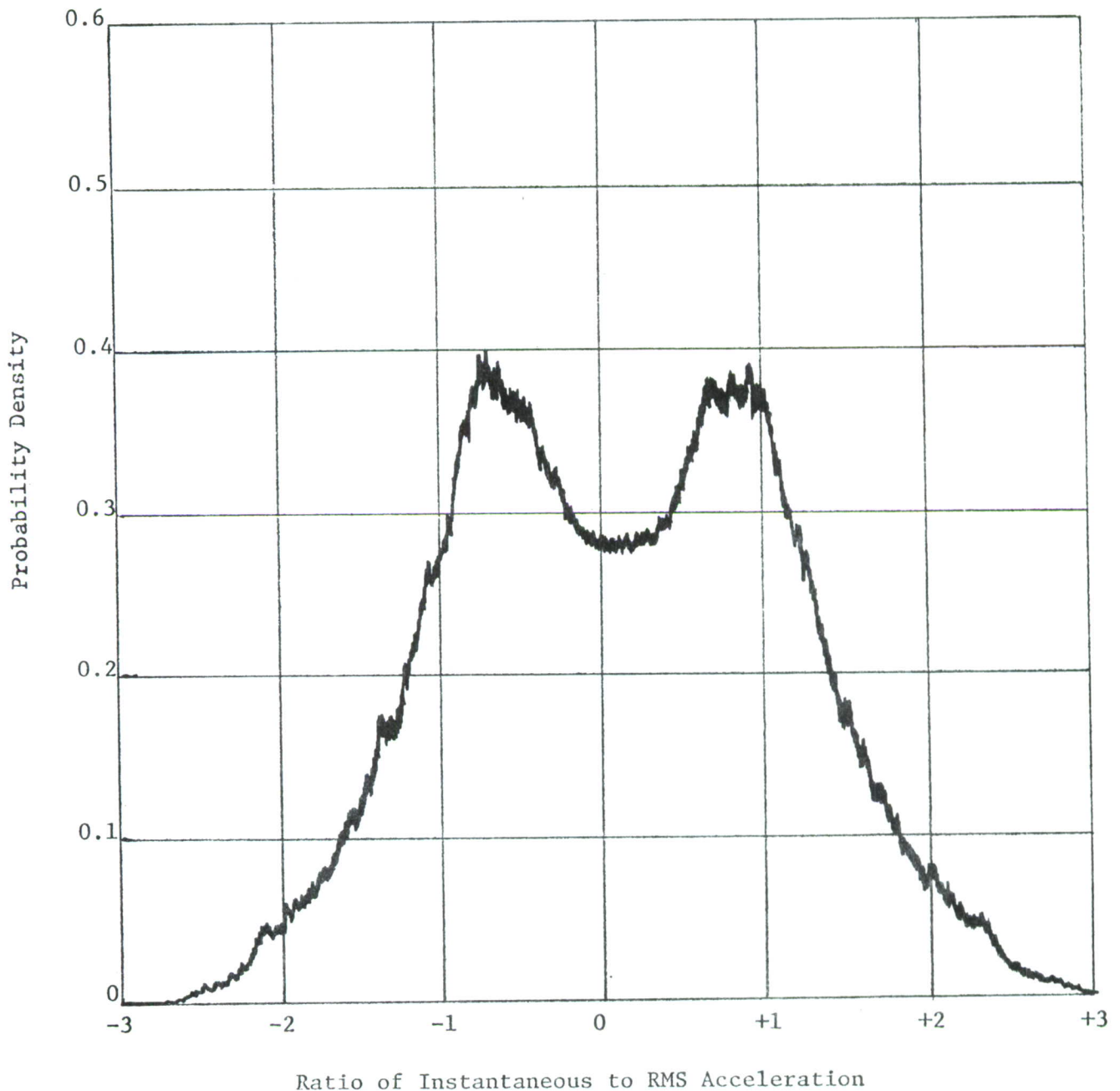


Figure 17. Acceleration APD, Rocket Salvo, 6 SPS, 105 Hz Center Frequency

Accelerometer Location: Pilot's Pedestal, Left Side, Sta. 122

Flight Condition: Rocket Salvo, Inboard Pylons, 6 SPS

Center Frequency: 520 Hz

Bandwidth: 5 Hz

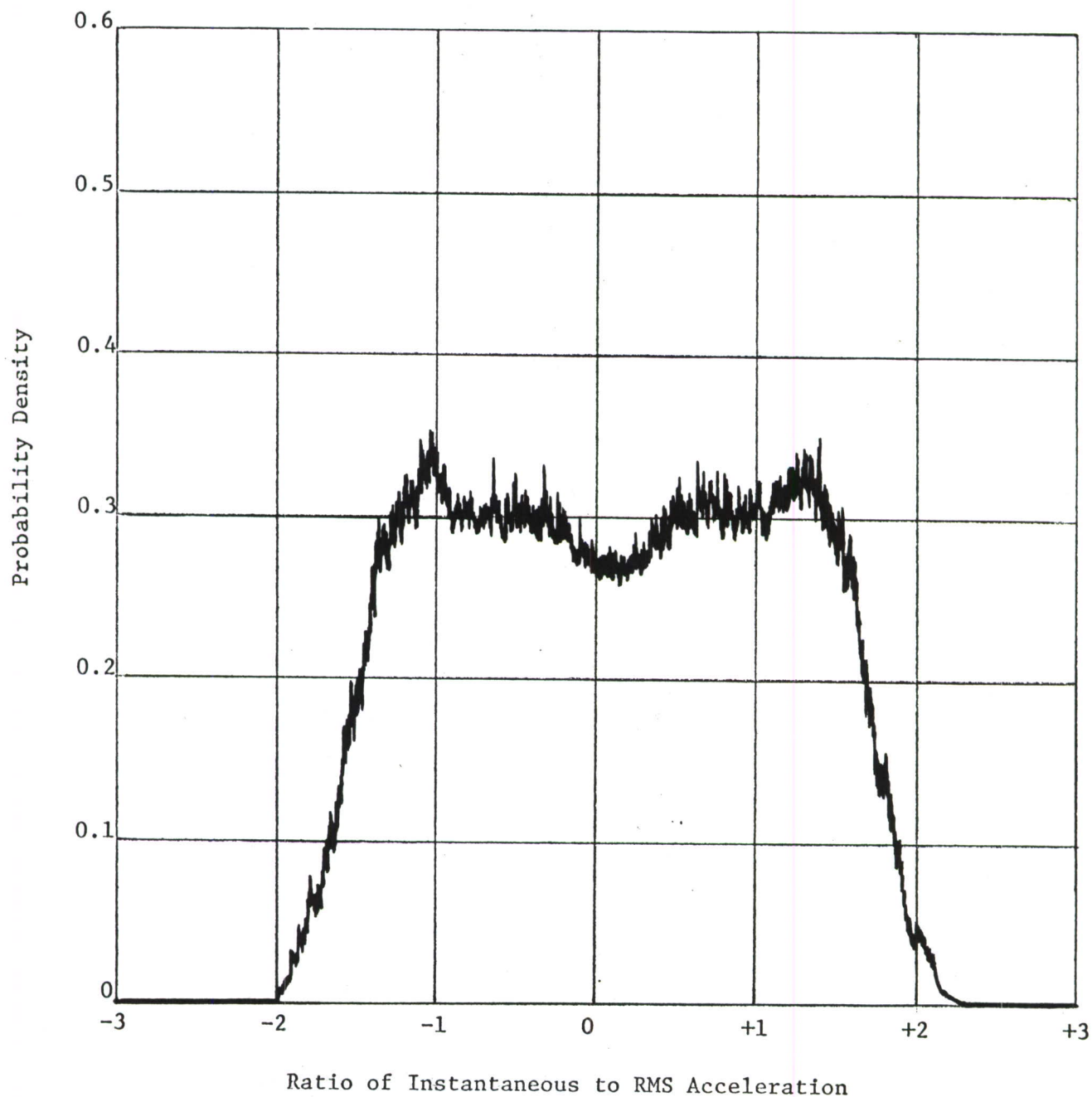


Figure 18. Acceleration APD, Rocket Salvo, 6 SPS, 520 Hz Center Frequency

Accelerometer Location: Pilot's Pedestal, Left Side, Sta. 122

Flight Condition: Rocket Salvo, Inboard Pylons, 6 SPS

Center Frequency: 1028 Hz

Bandwidth: 20 Hz

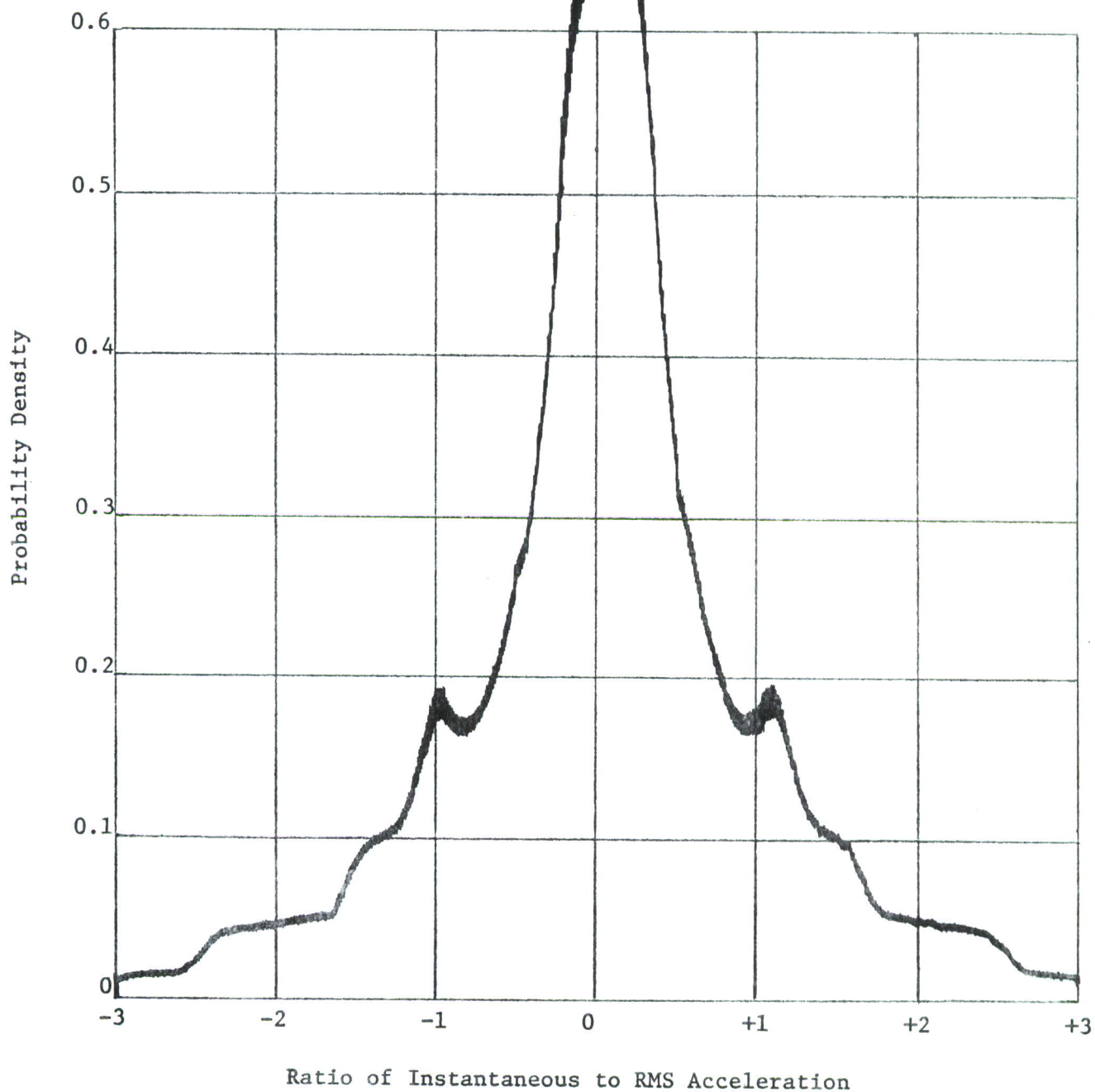


Figure 19. Acceleration APD, Rocket Salvo, 6 SPS, 1028 Hz Center Frequency

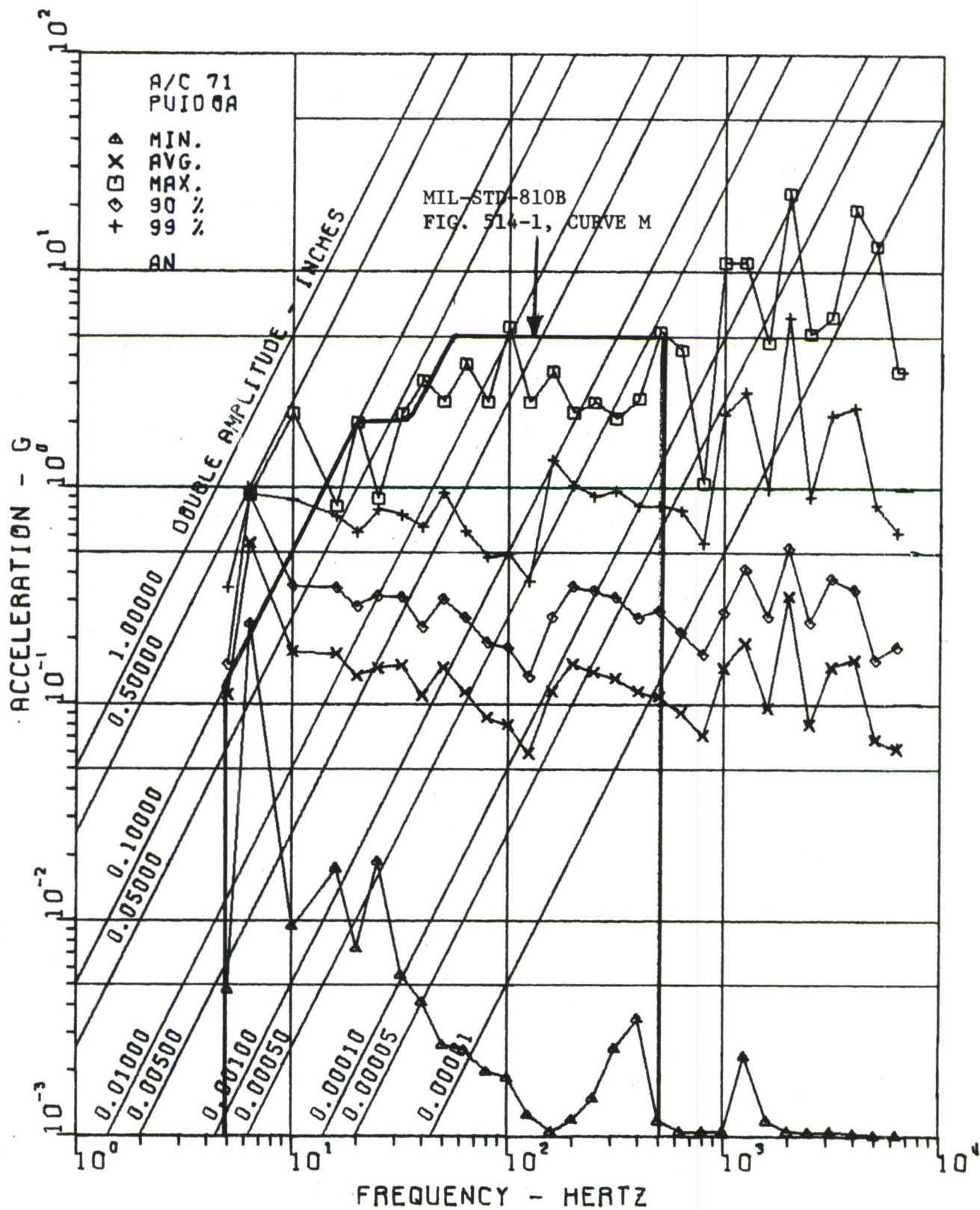


Figure 20. Entire Helicopter, Without Gunfire

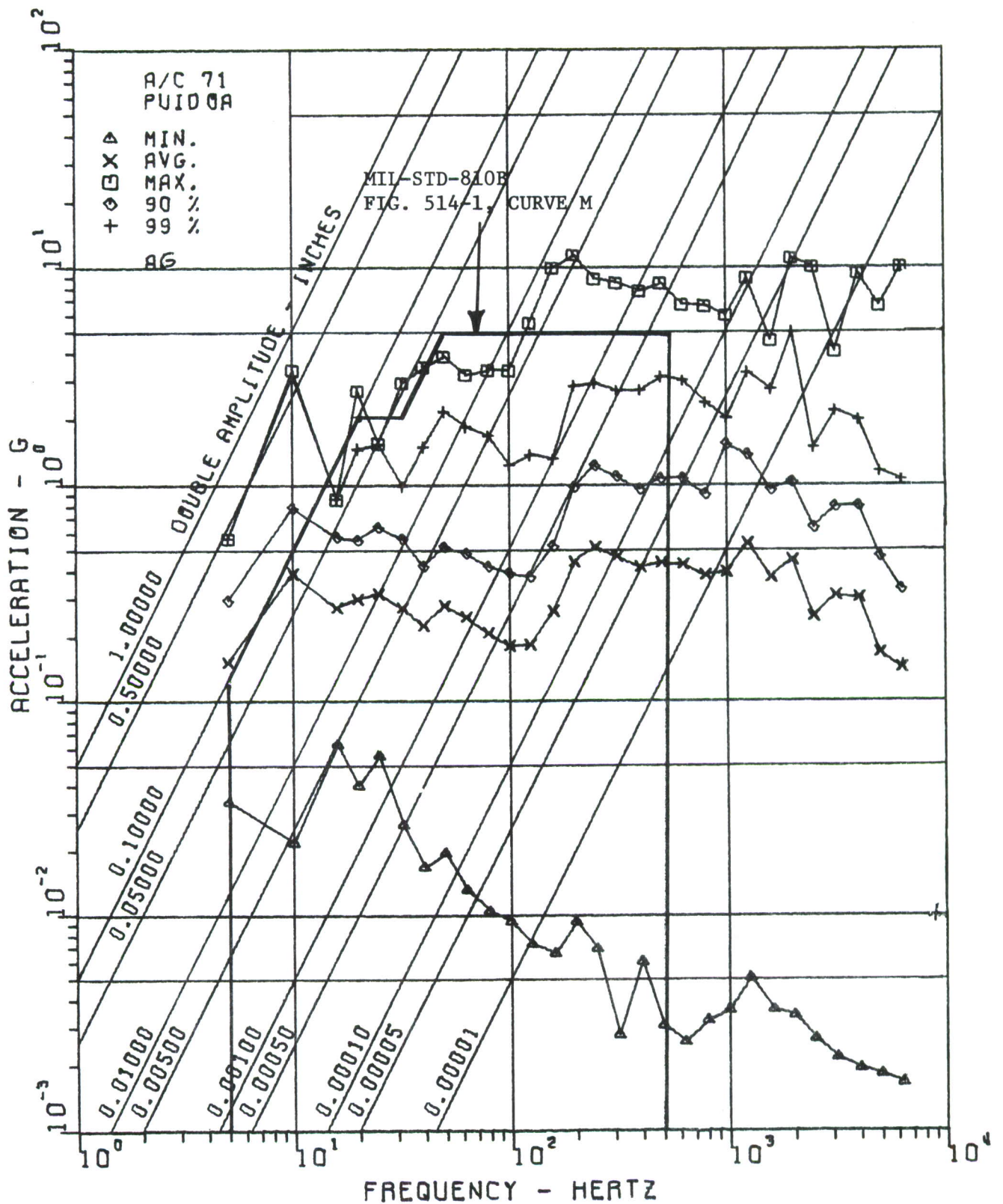


Figure 21. Entire Helicopter, With Gunfire

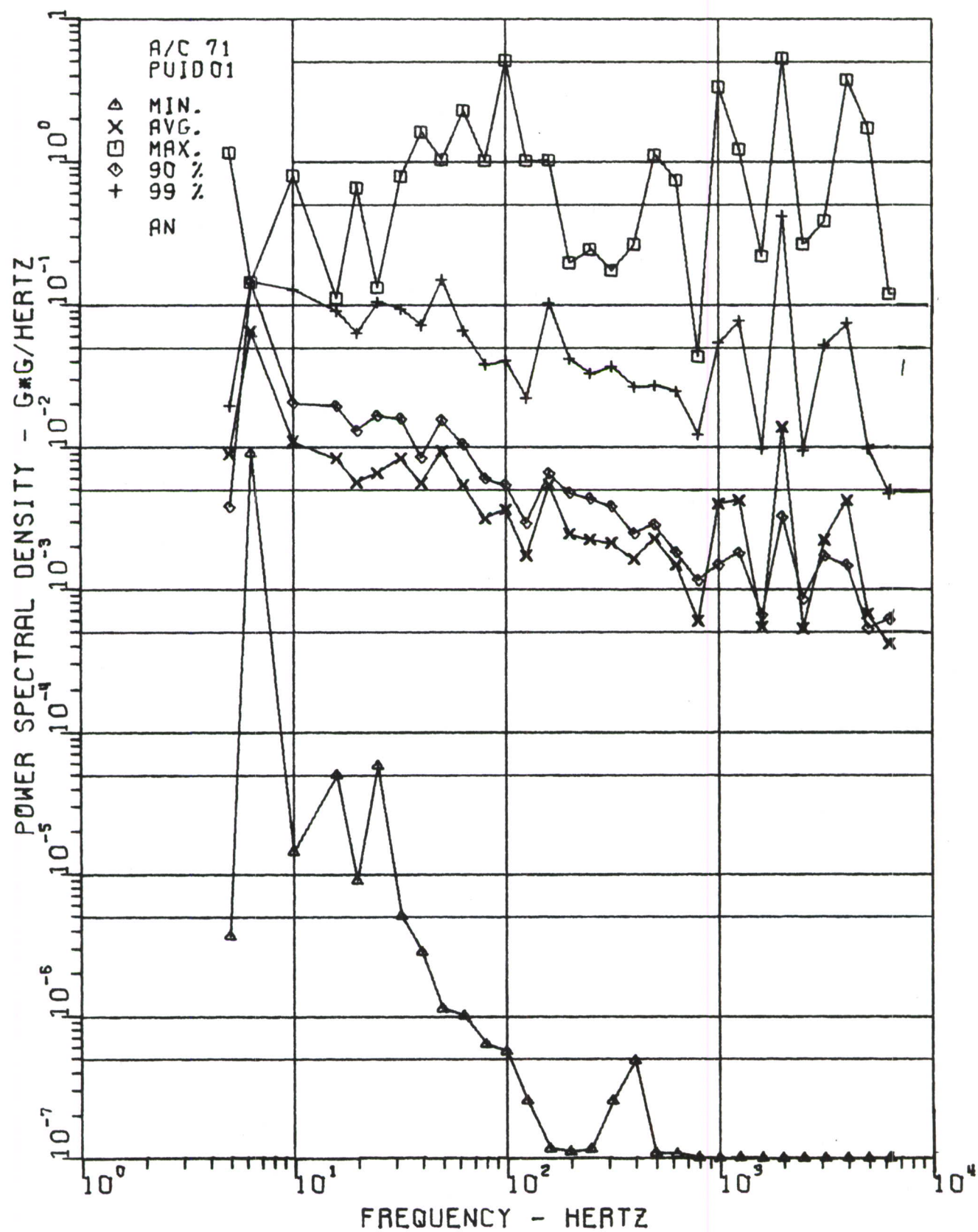


Figure 22. Entire Helicopter, Without Gunfire

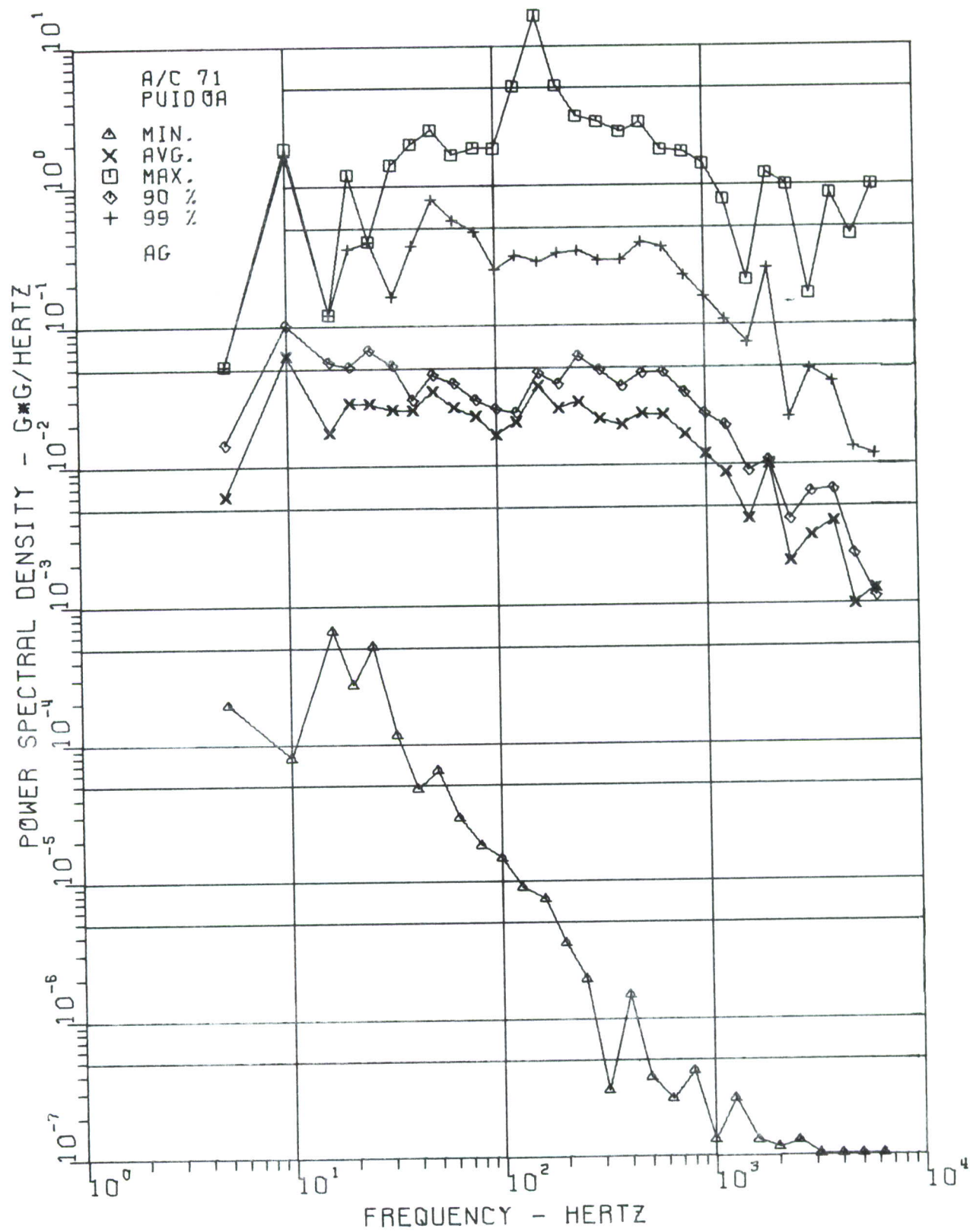


Figure 23. Entire Helicopter, With Gunfire

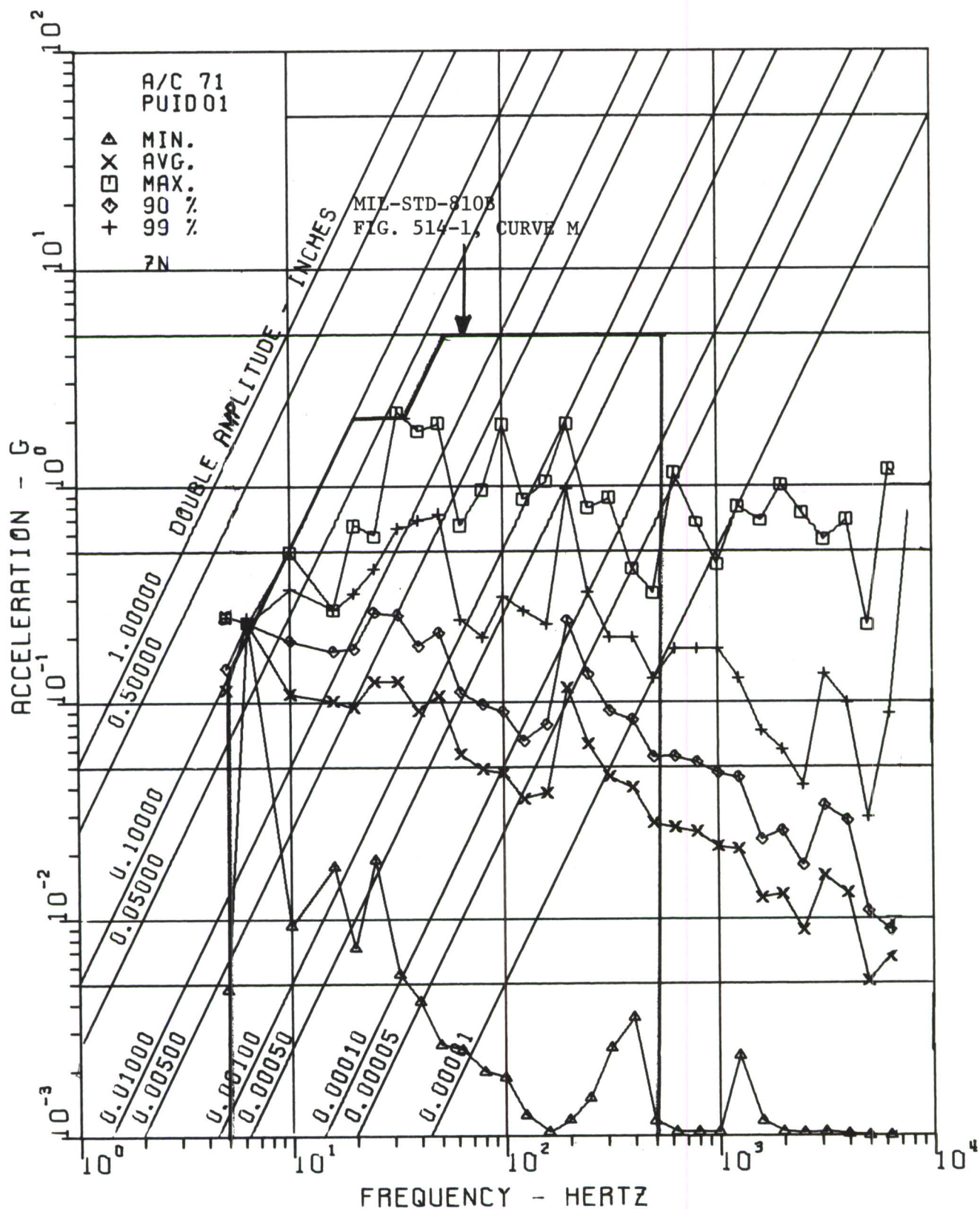


Figure 24. Nose and Cockpit Sections, Fuselage Stations 0-170, Without Gunfire

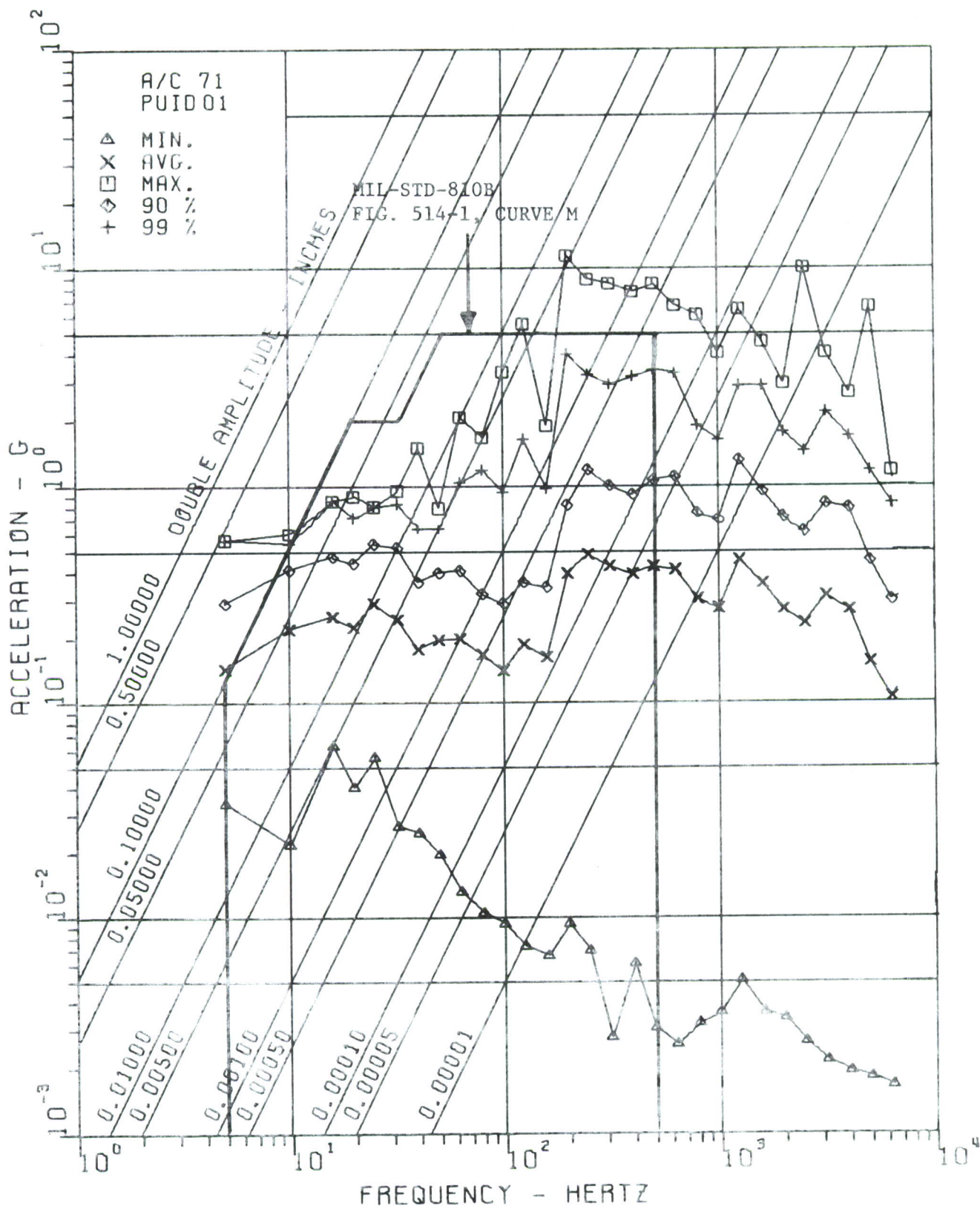


Figure 25. Nose and Cockpit Sections, Fuselage Stations 0-170, with Gunfire

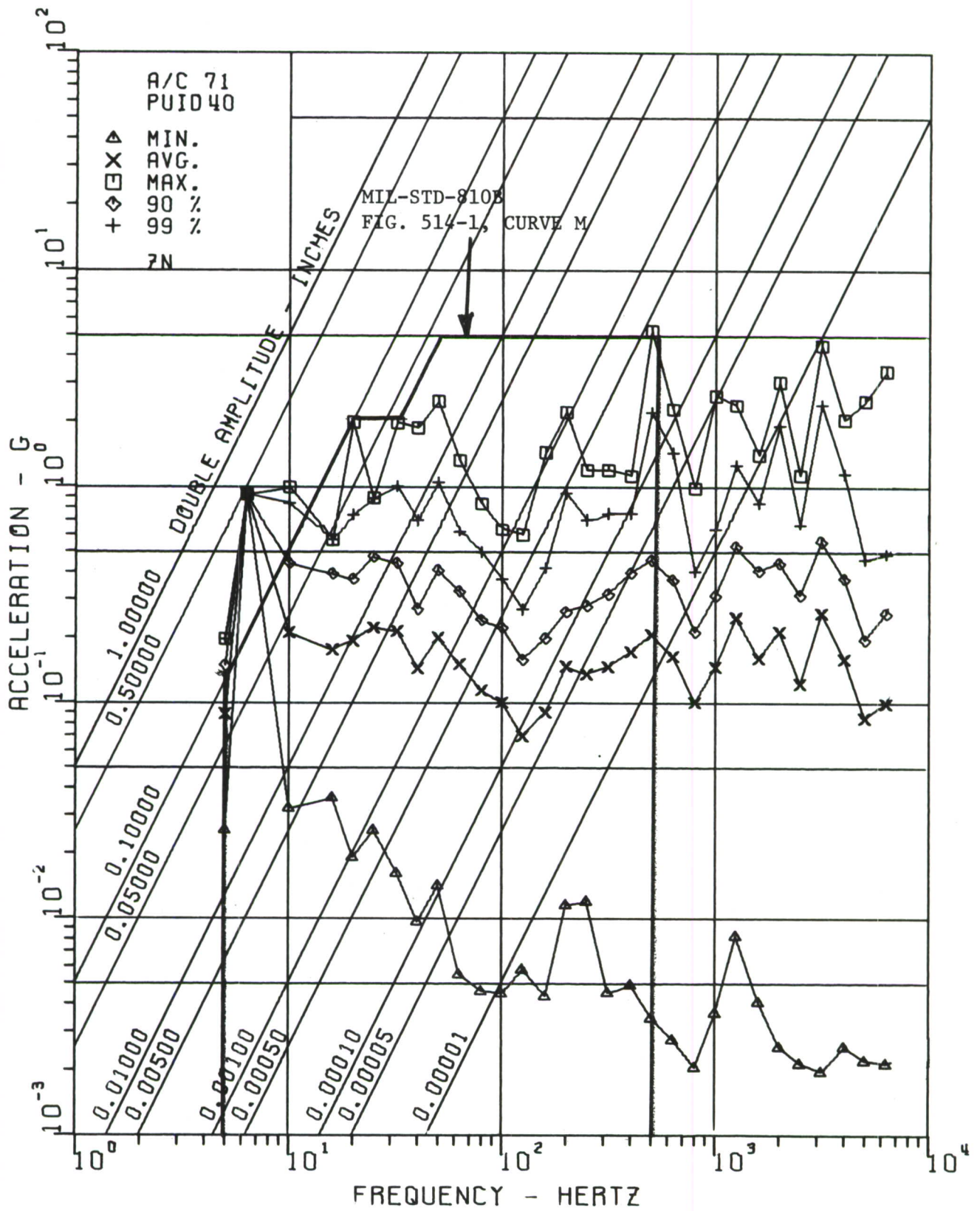


Figure 26. Engine-Transmission Section, Fuselage Stations 171-270, Without Gunfire

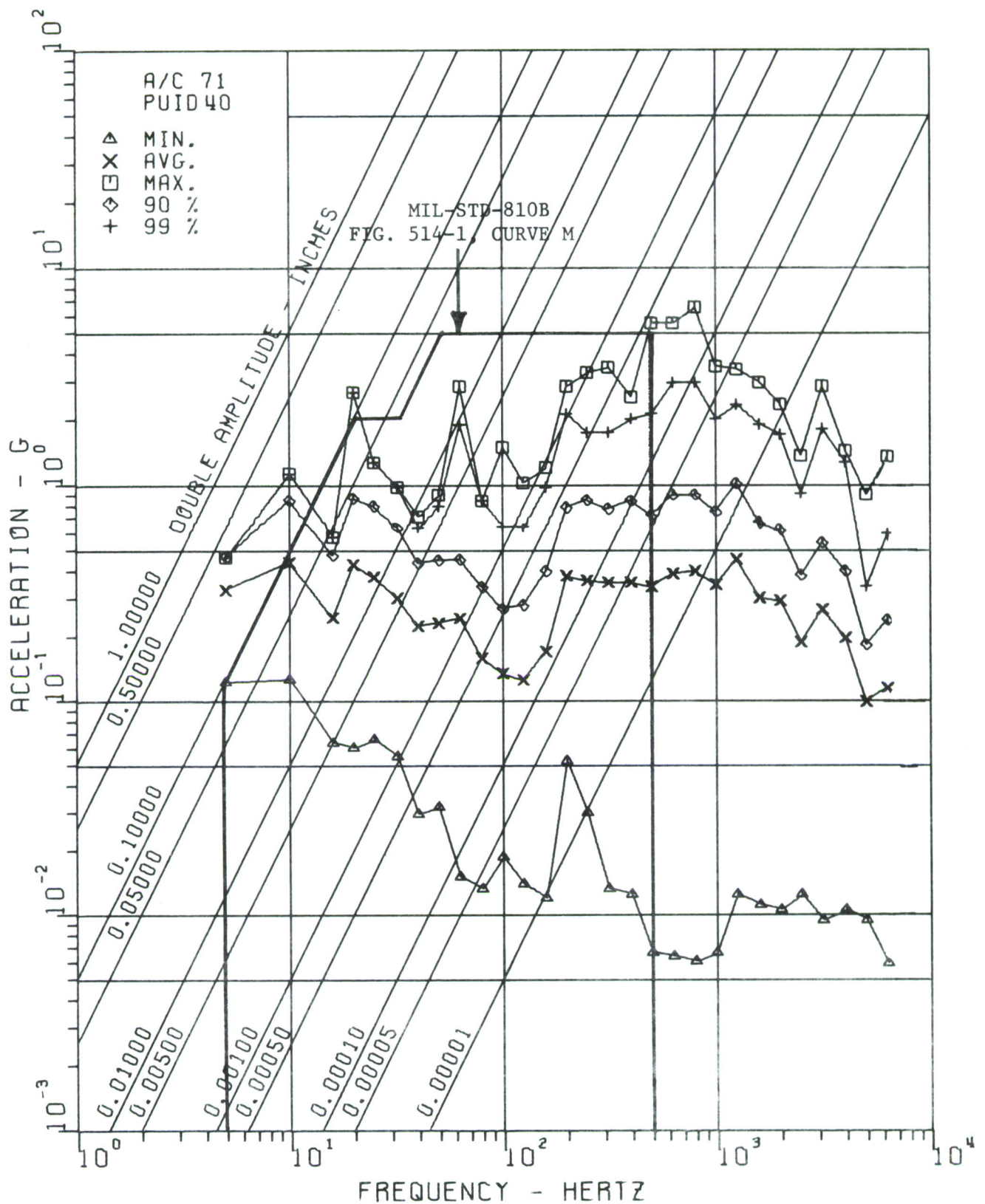


Figure 27. Engine-Transmission Section, Fuselage Stations 171-270, with Gunfire

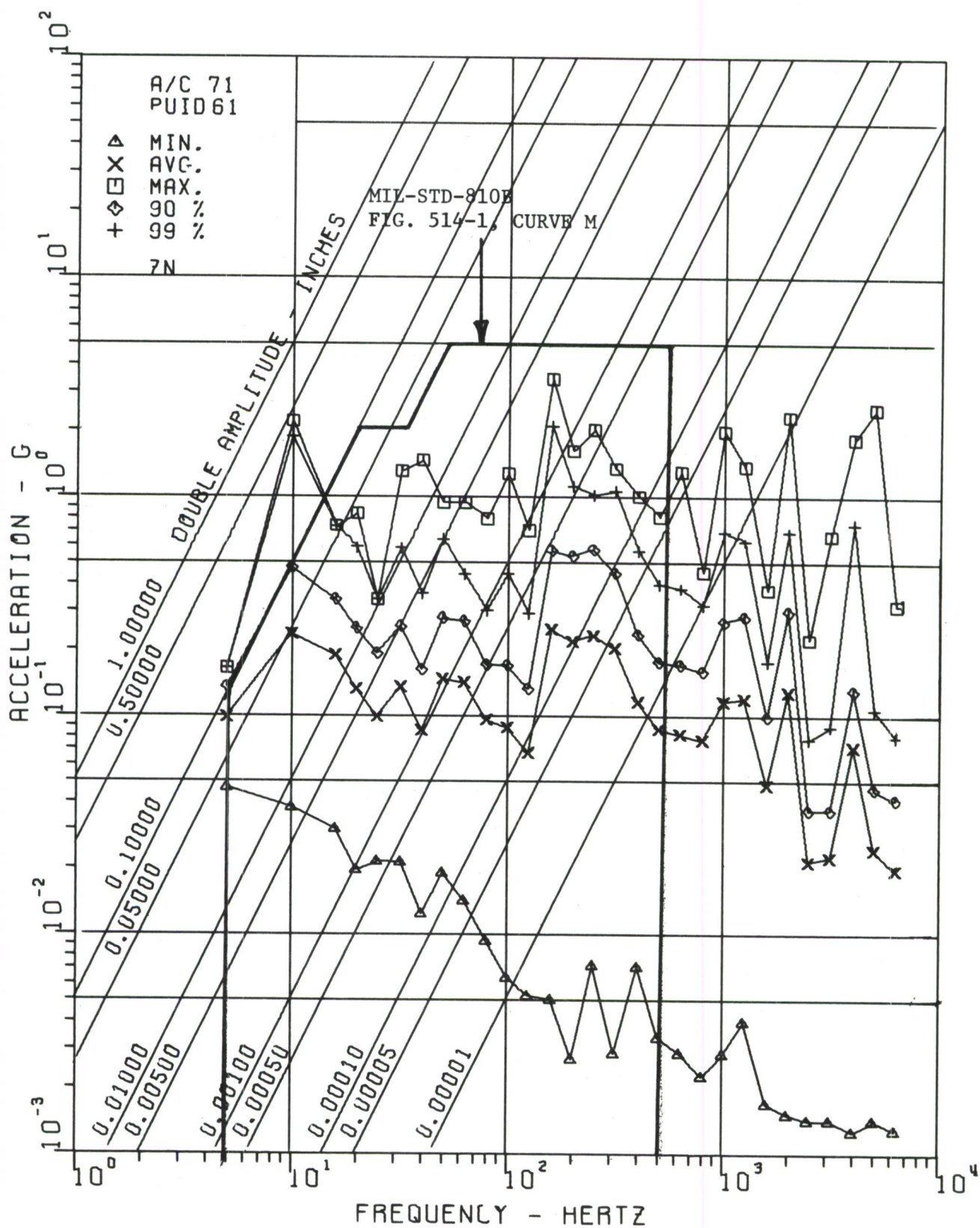


Figure 28. Aft Electrical and Radio Sections, Fuselage Stations 271-390, Without Gunfire

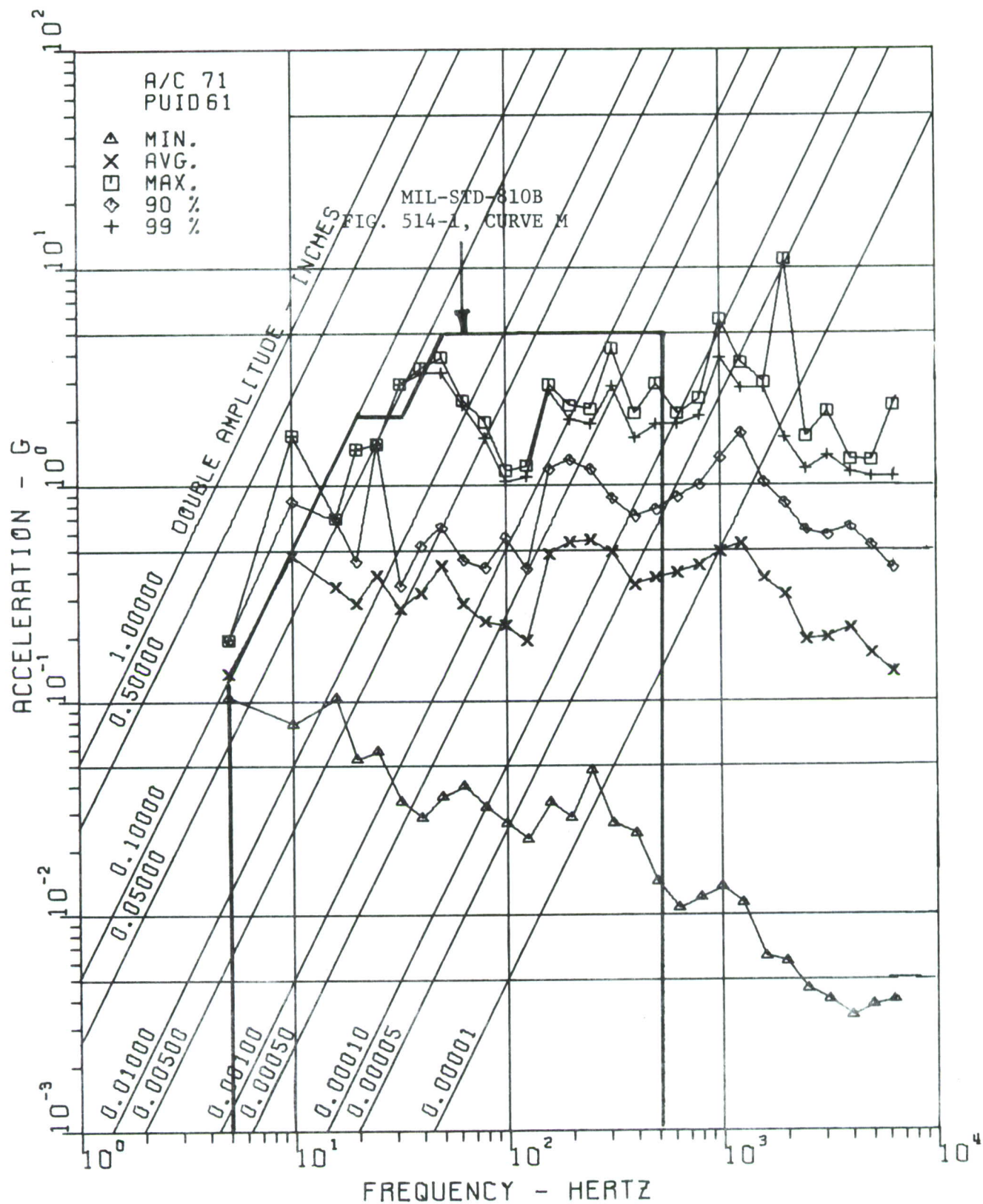


Figure 29. Aft Electrical and Radio Sections, Fuselage Stations 271-390, with Gunfire

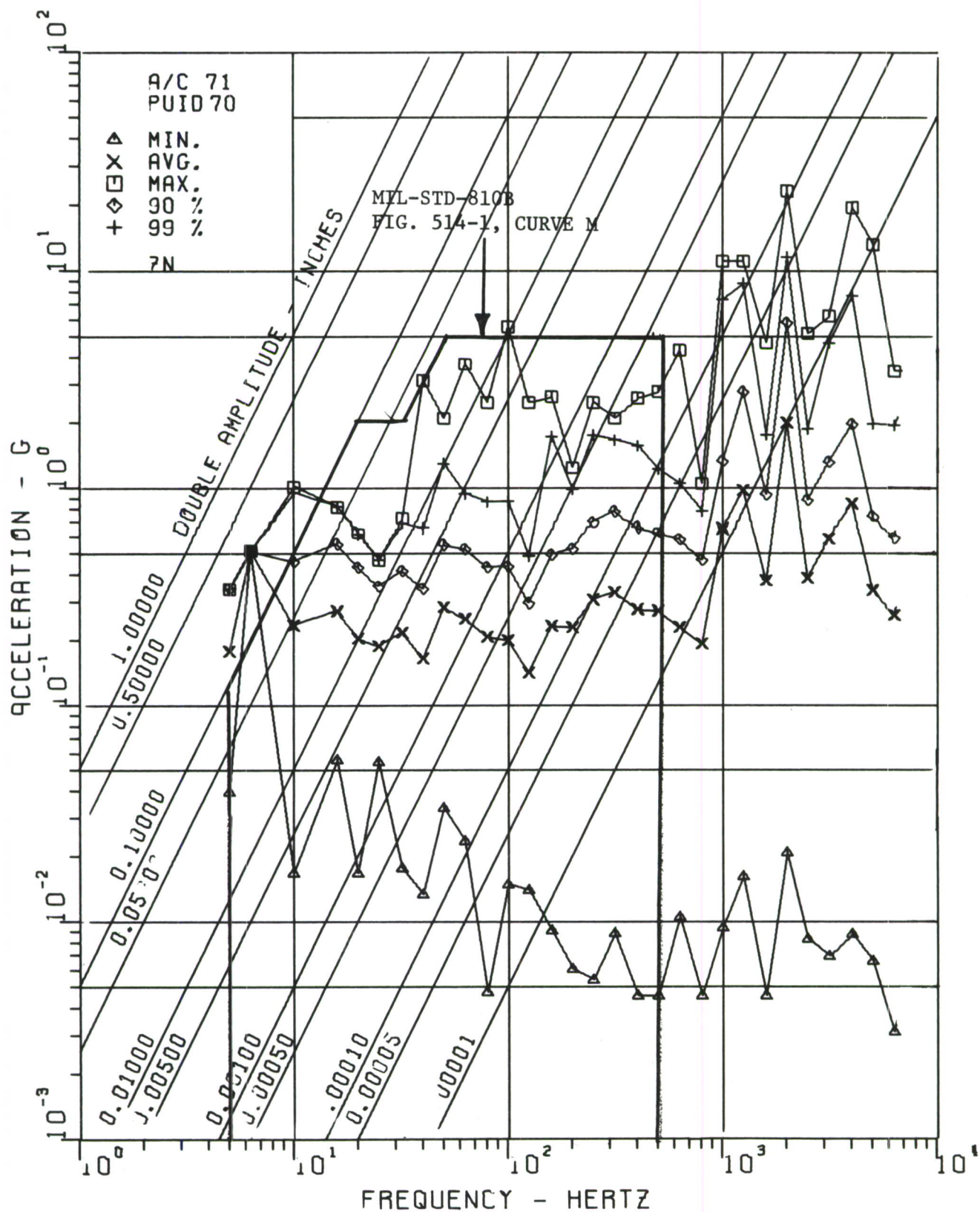


Figure 30. Aft Tail Boom Section, Fuselage Stations 391-560,
Without Gunfire

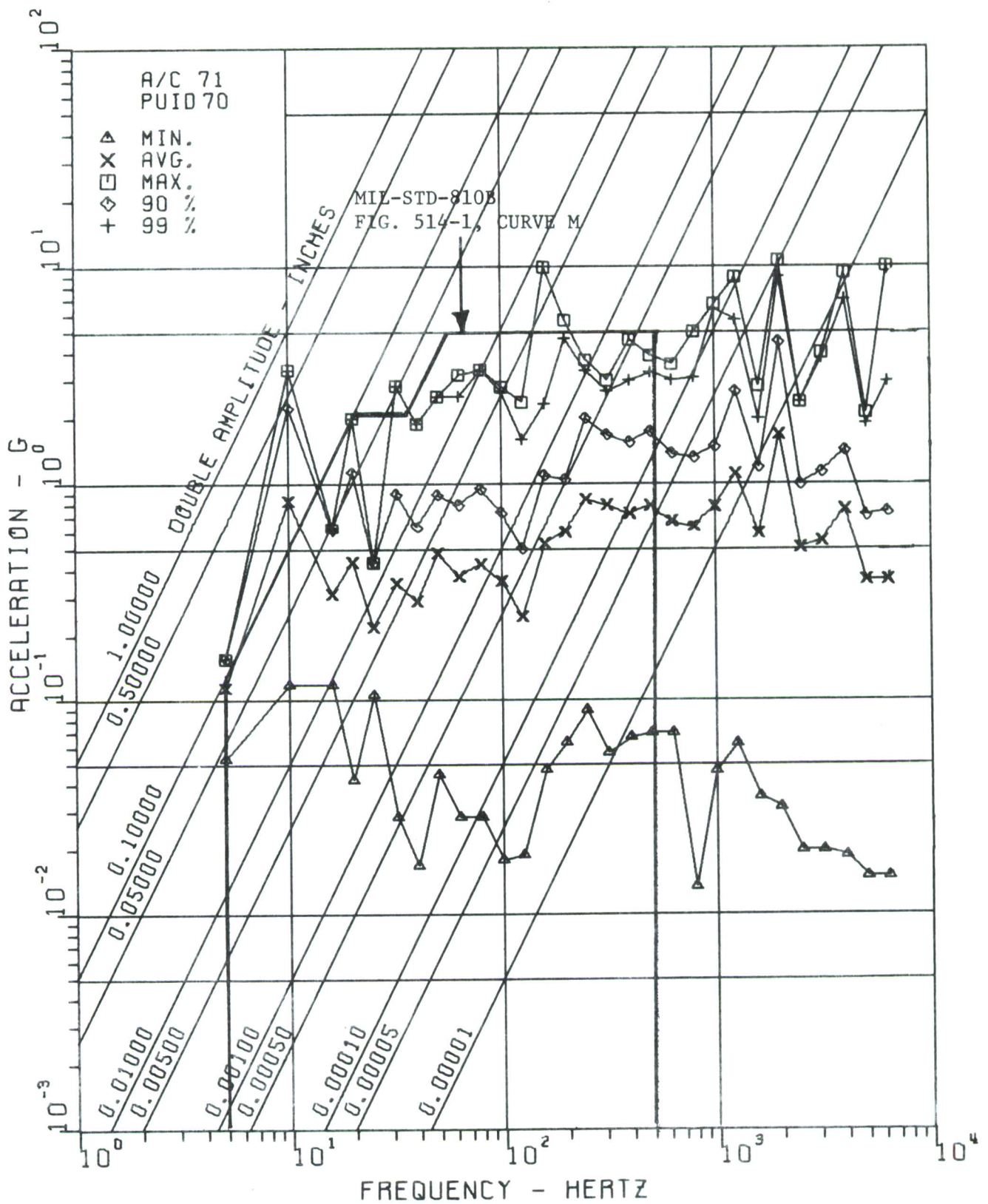


Figure 31. Aft Tail Boom Section, Fuselage Stations 391-560,
with Gunfire

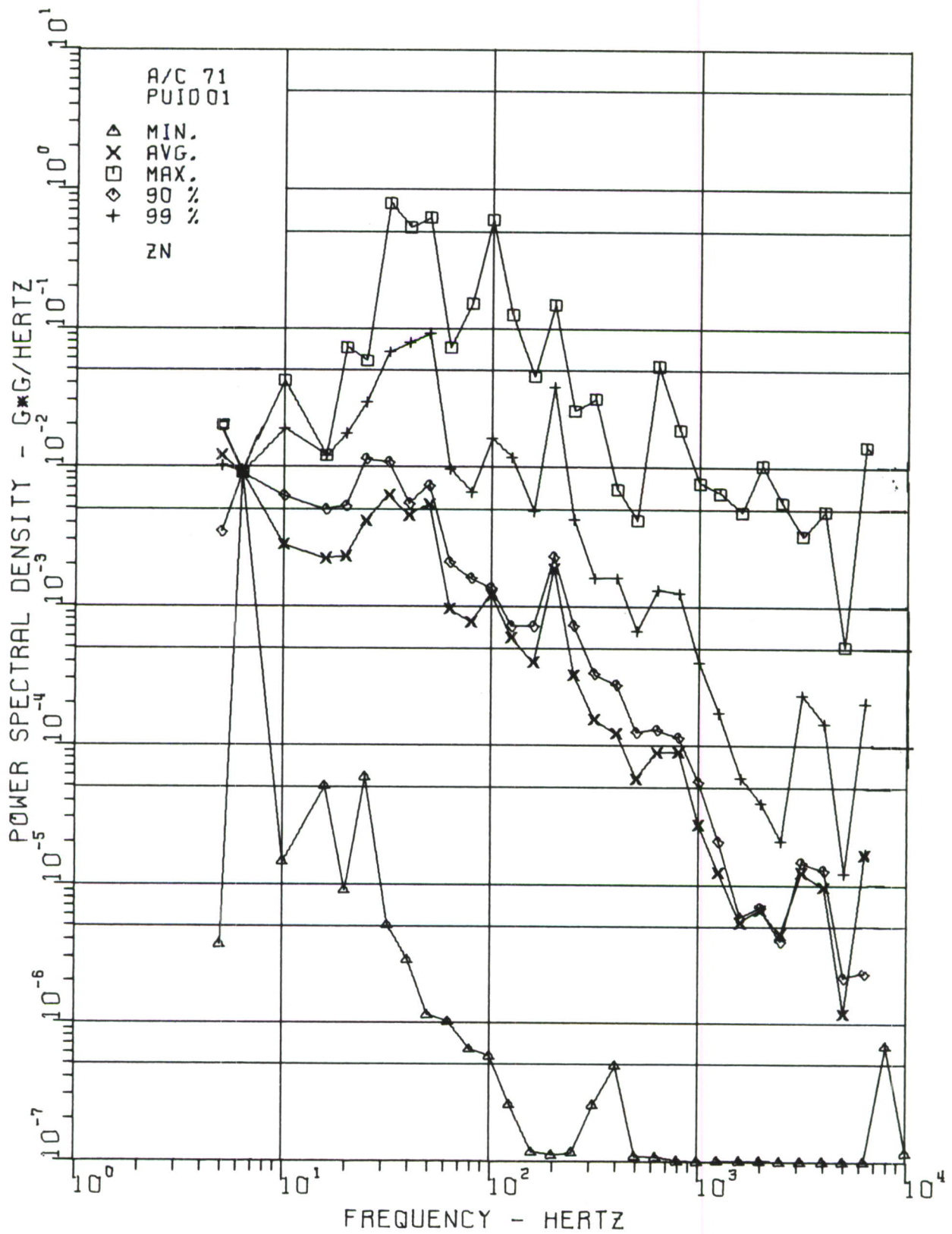


Figure 32. Nose and Cockpit Sections, Fuselage Stations 0-170, without Gunfire

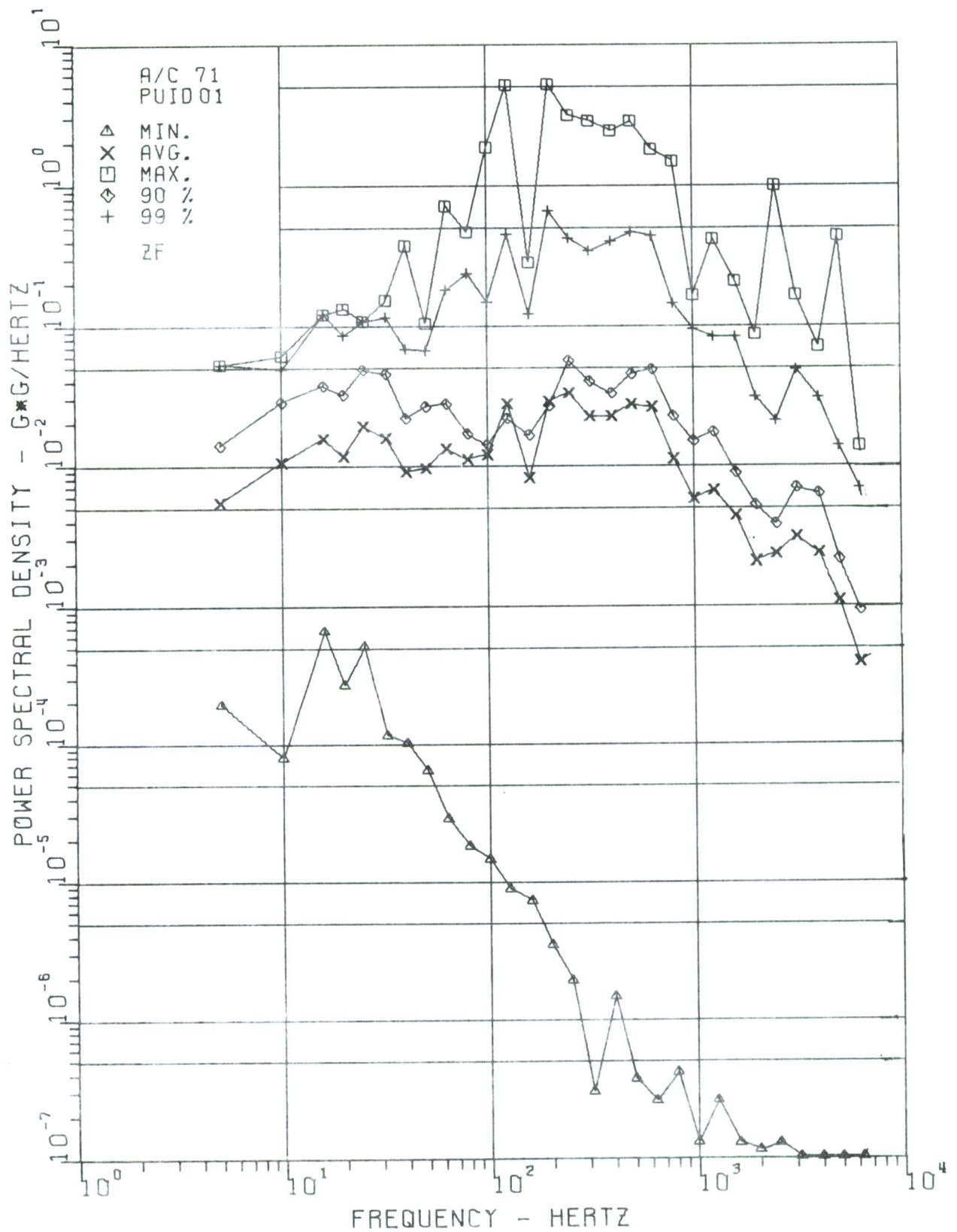


Figure 33. Nose and Cockpit Sections, Fuselage Stations 0-170, with Gunfire

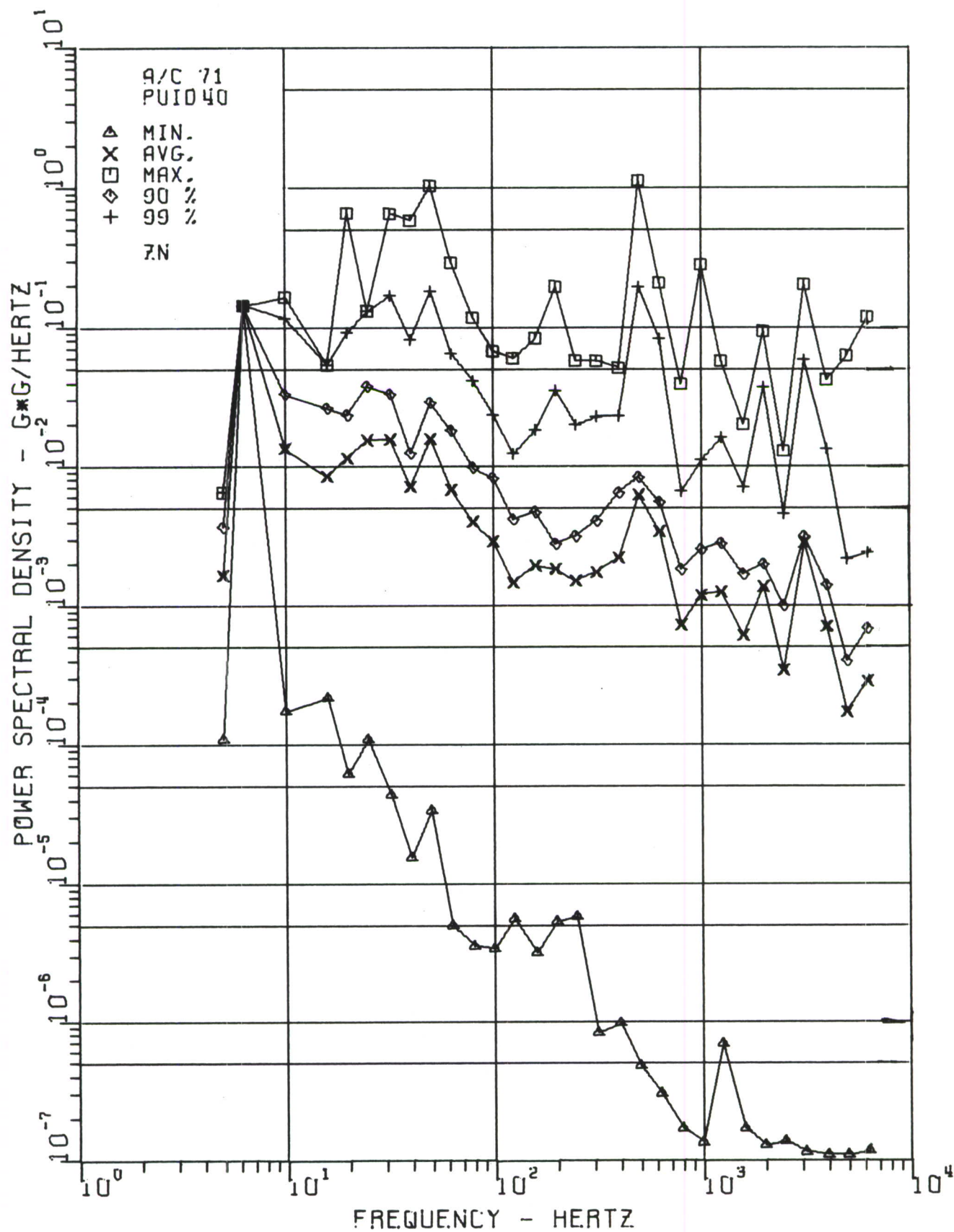


Figure 34. Engine-Transmission Section, Fuselage Stations 171-270, without Gunfire

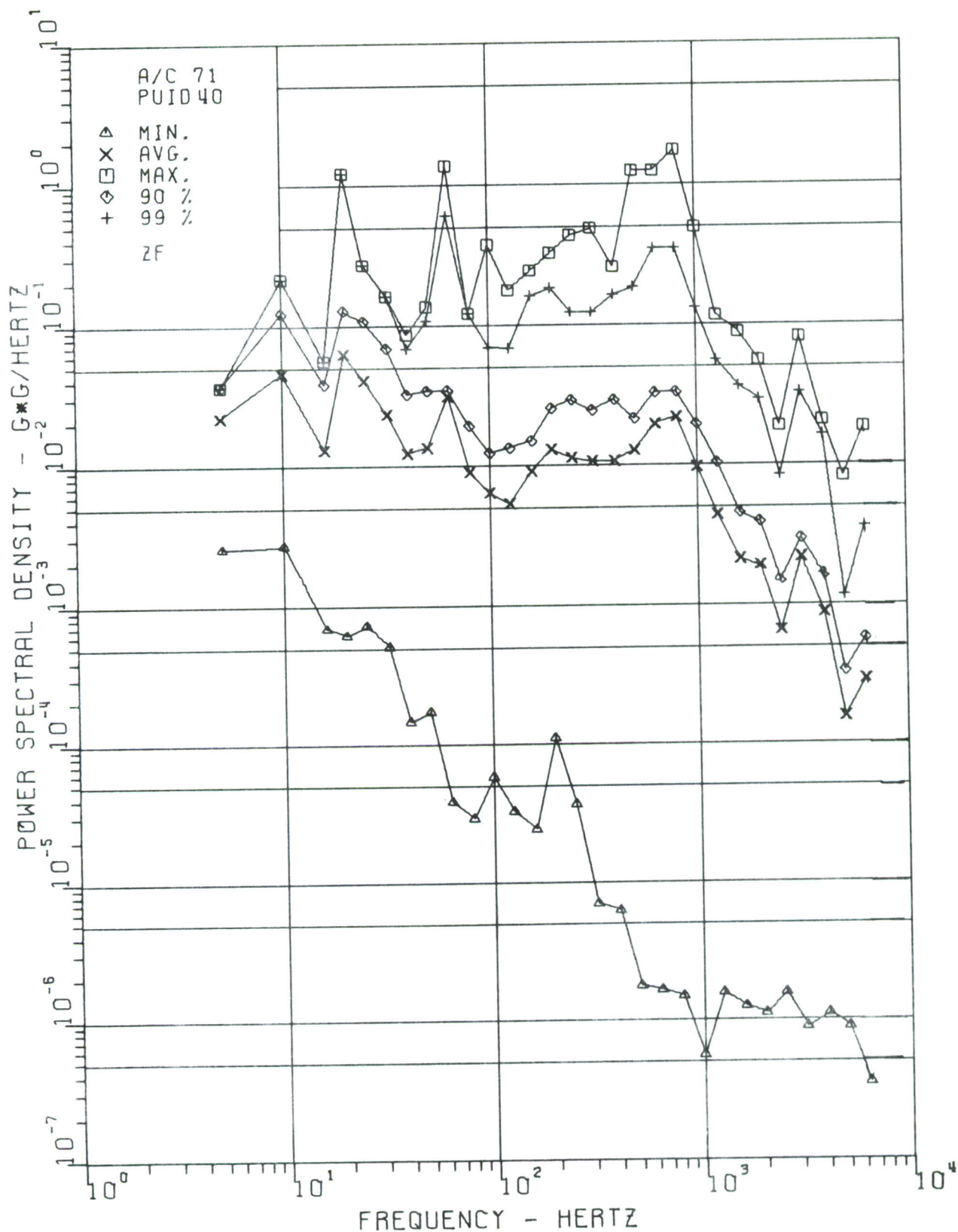


Figure 35. Engine-Transmission Section, Fuselage Stations 171-270, with Gunfire

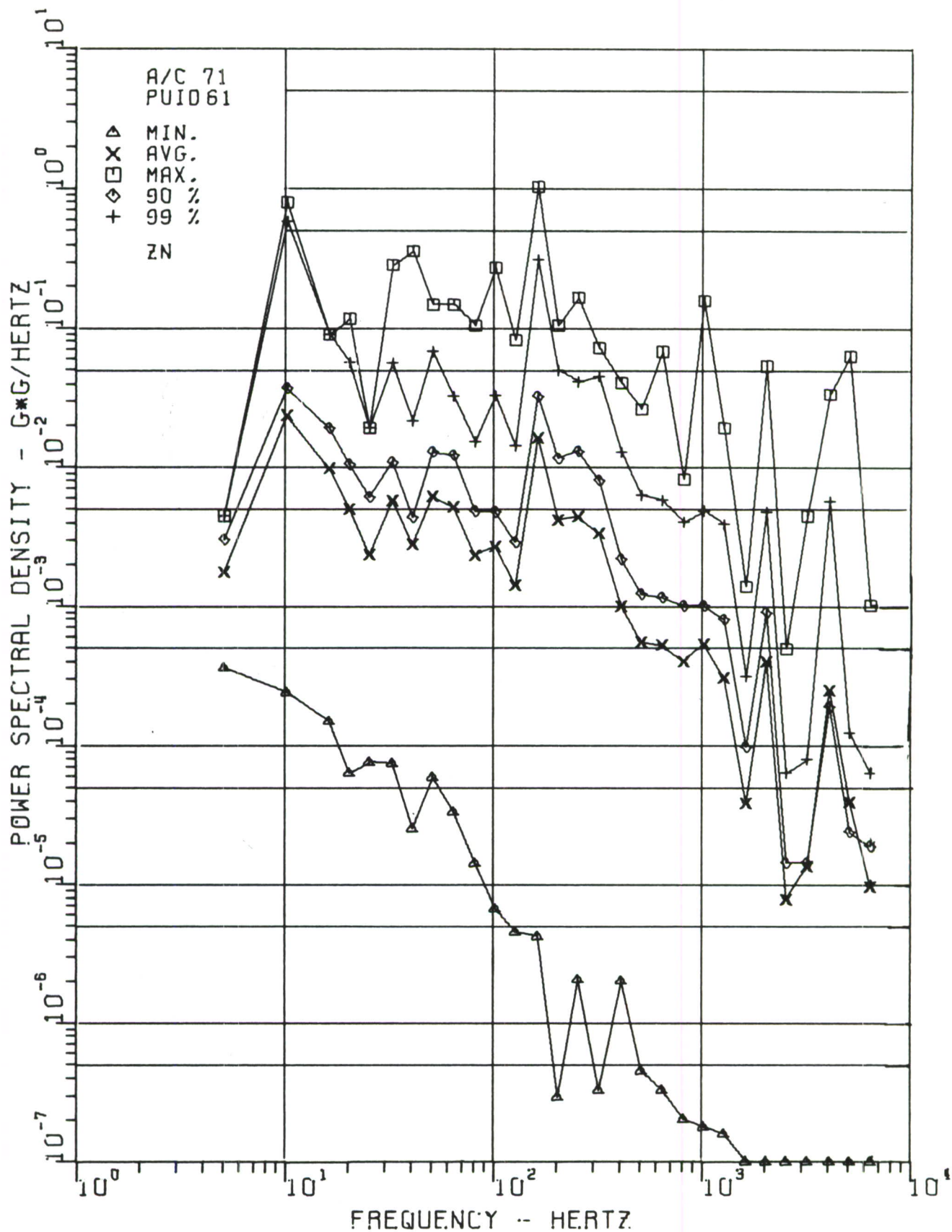


Figure 36. Aft Electrical and Radio Sections, Fuselage Stations 271-390, without Gunfire

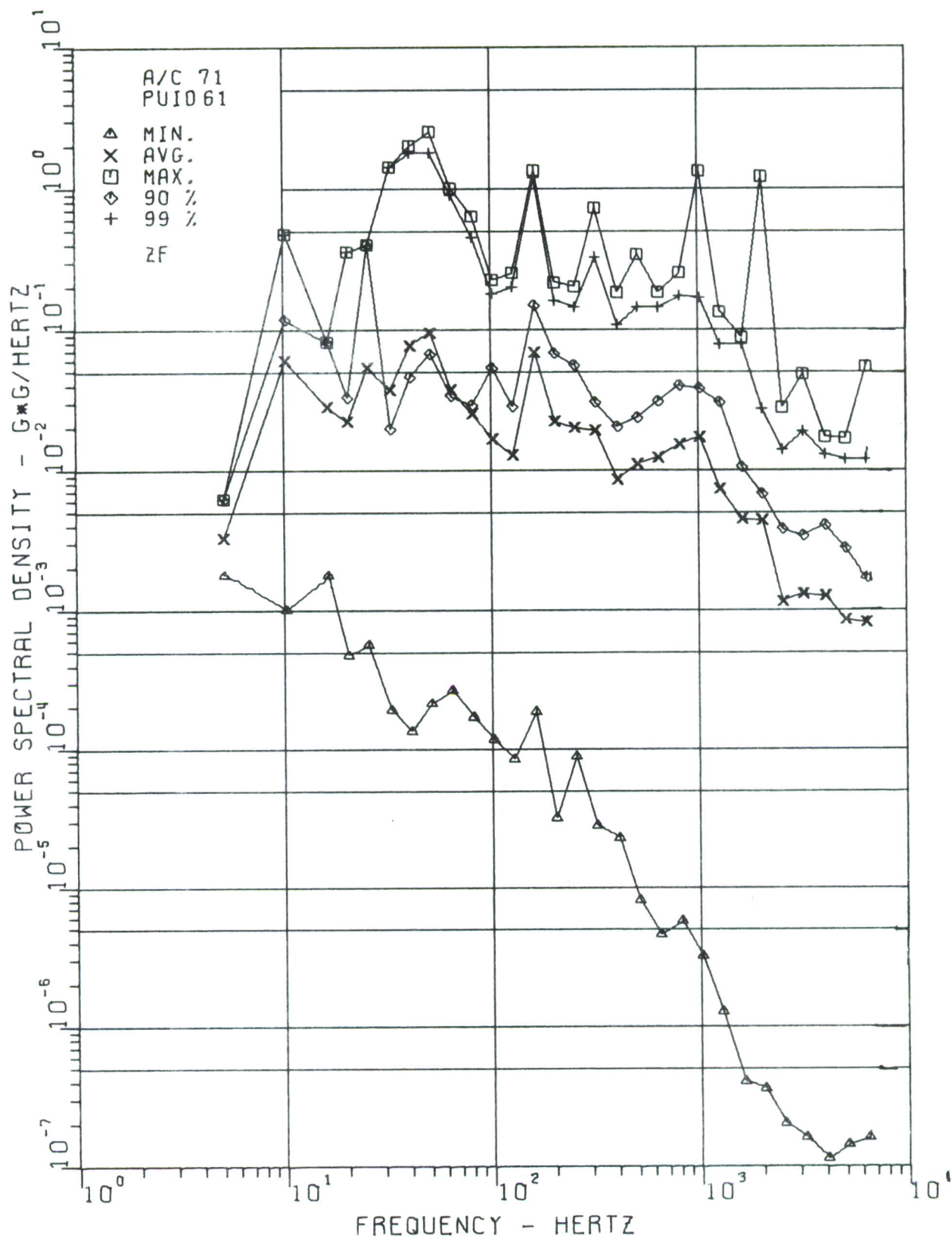


Figure 37. Aft Electrical and Radio Sections, Fuselage Stations 271-390, with Gunfire

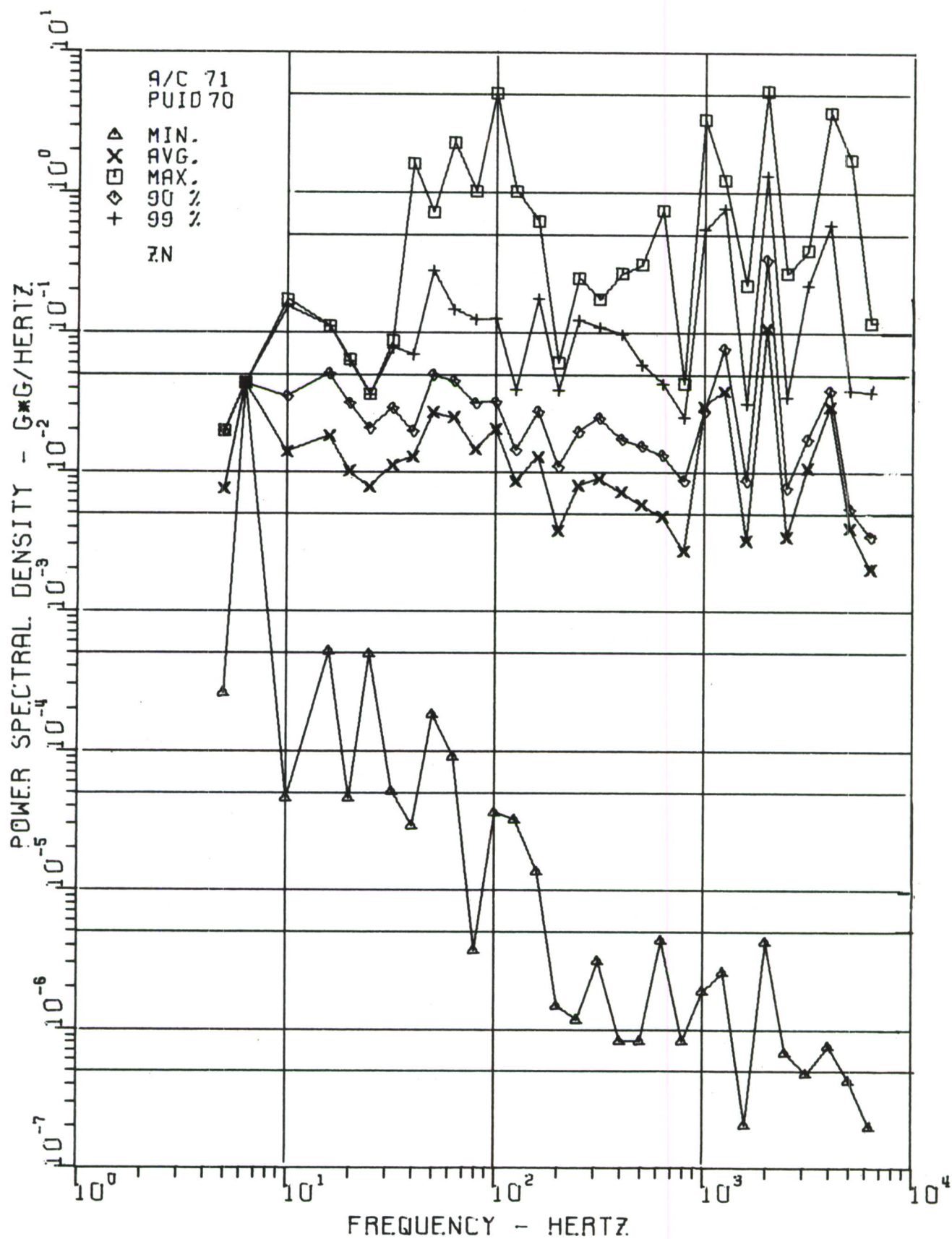


Figure 38. Aft Tail Boom Section, Fuselage Stations 391-560, without Gunfire

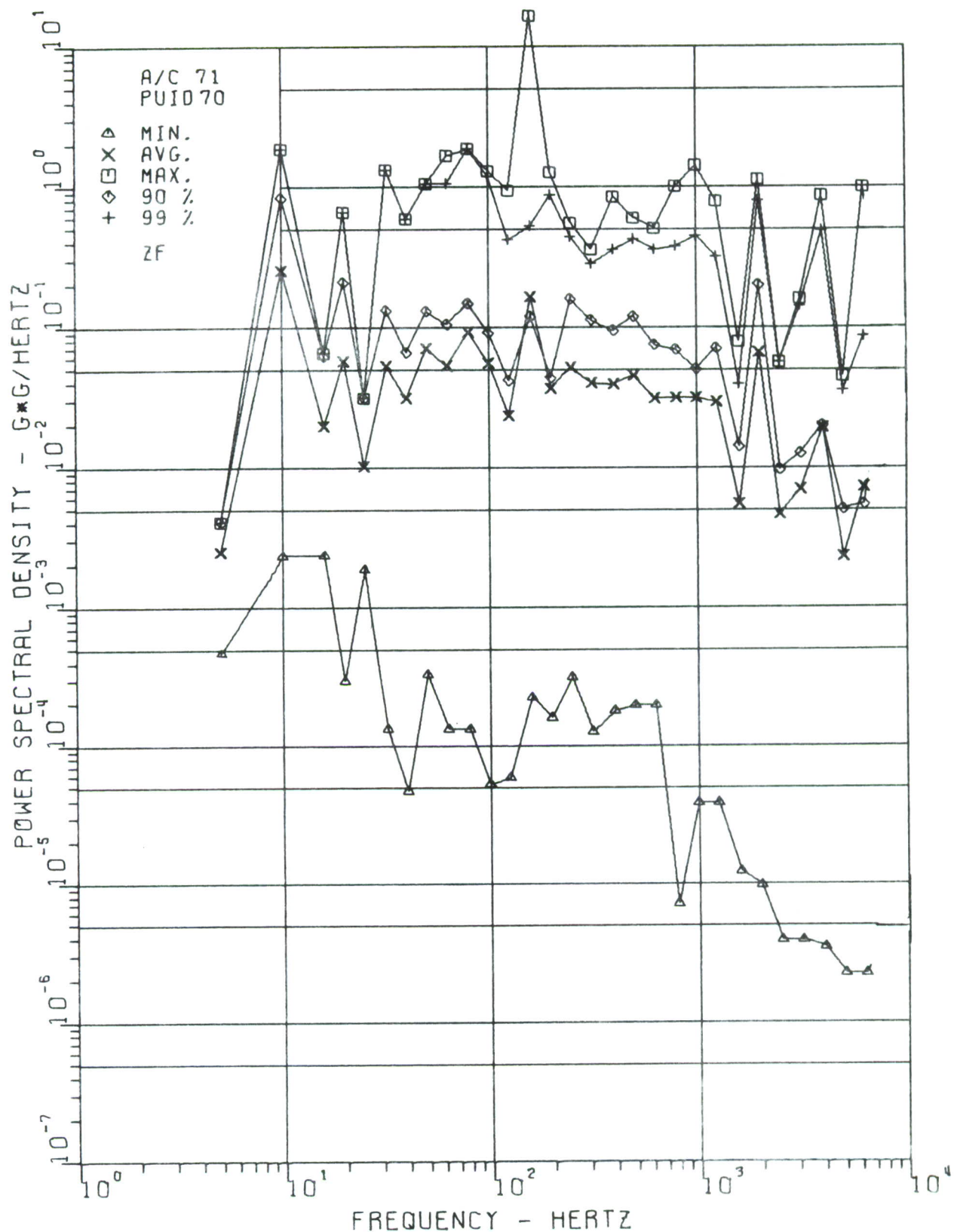


Figure 39. Aft Tail Boom Section, Fuselage Stations 391-560, with Gunfire

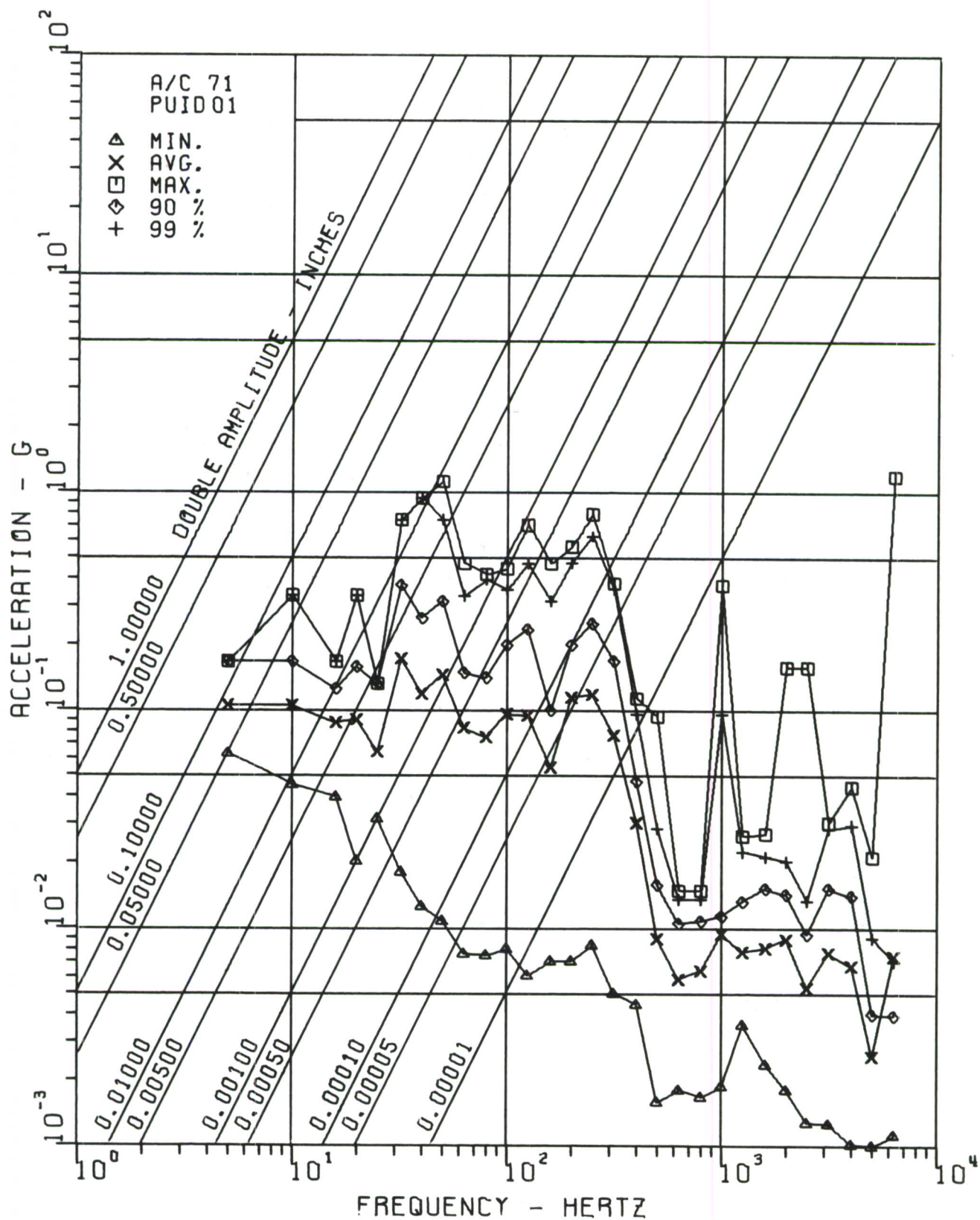


Figure 40. Gunner's Instrument Panel, Left Side, Sta. 60, without Gunfire

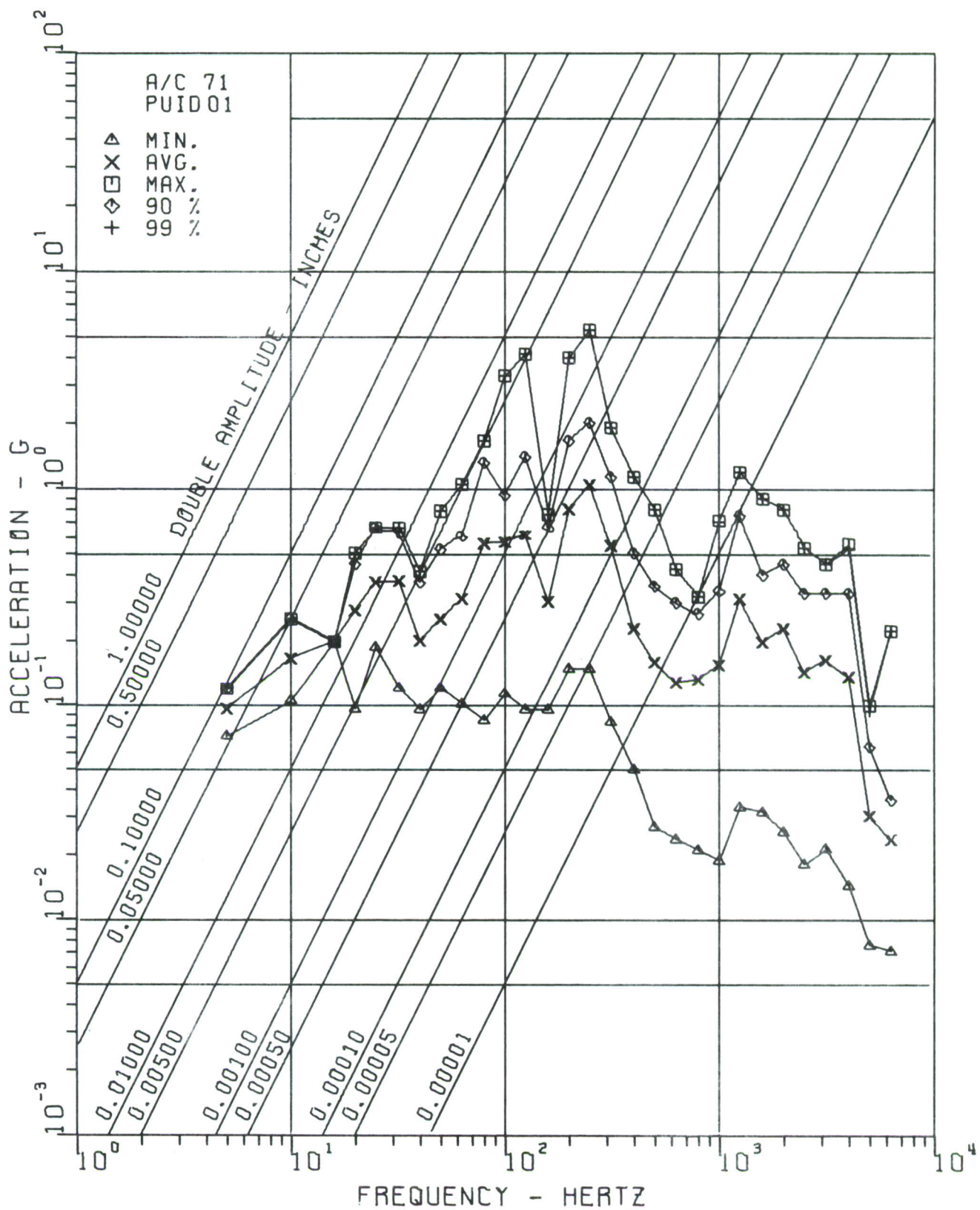


Figure 41. Gunner's Instrument Panel, Left Side, Sta. 60 , with Gunfire

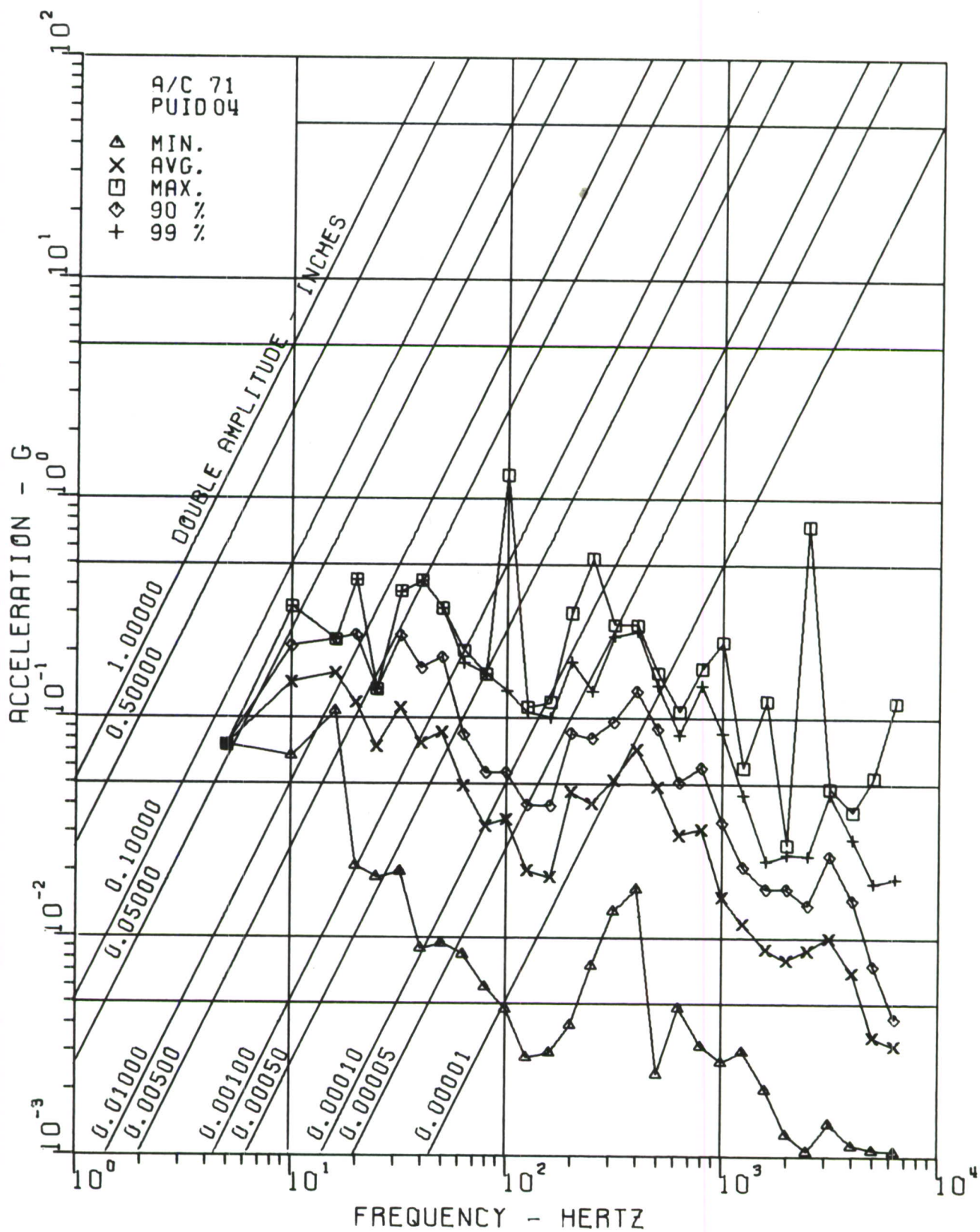


Figure 42. Gunner's Pedestal, Left Side, Sta. 65, without Gunfire

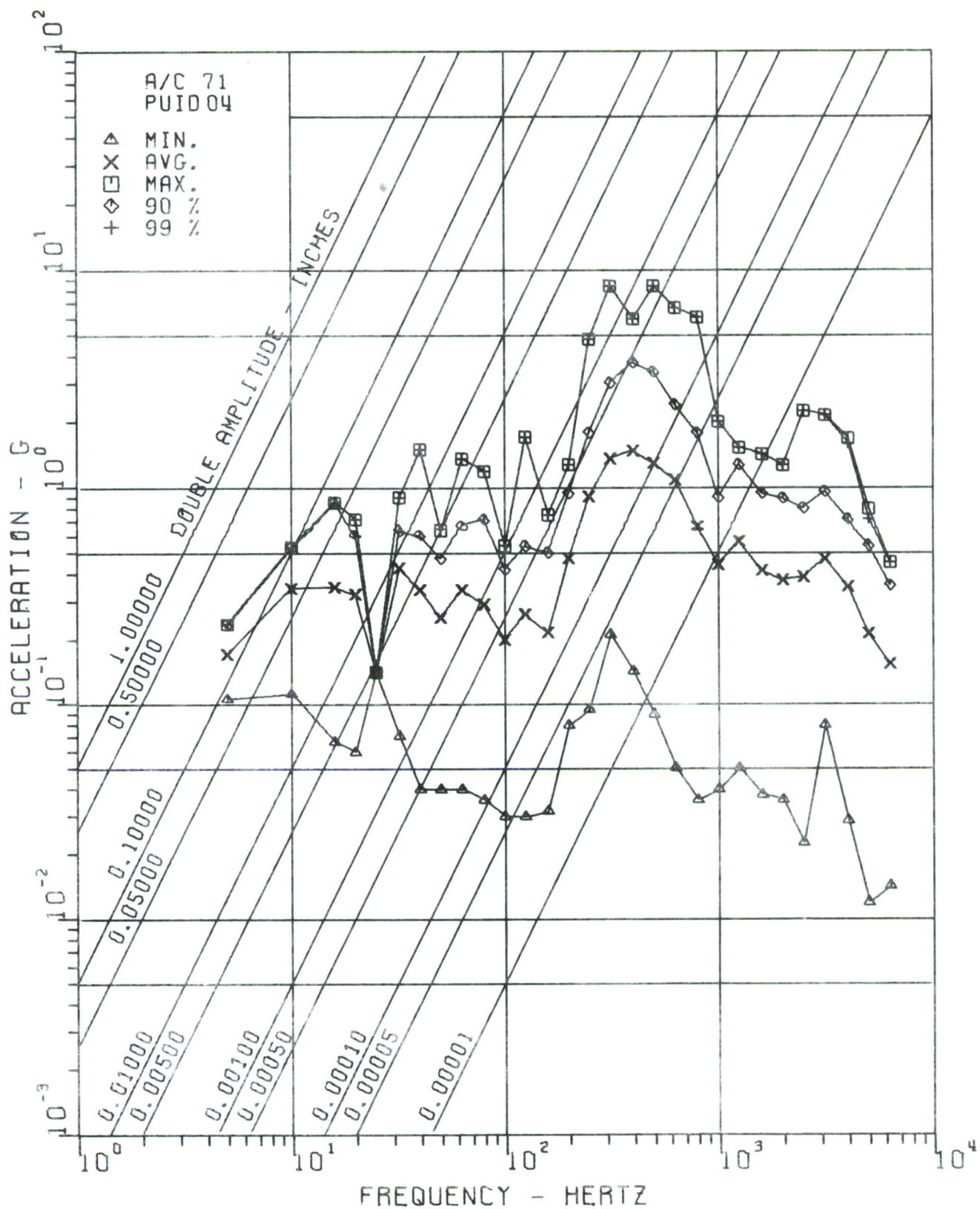


Figure 43. Gunner's Pedestal, Left Side, Sta. 65, with Gunfire

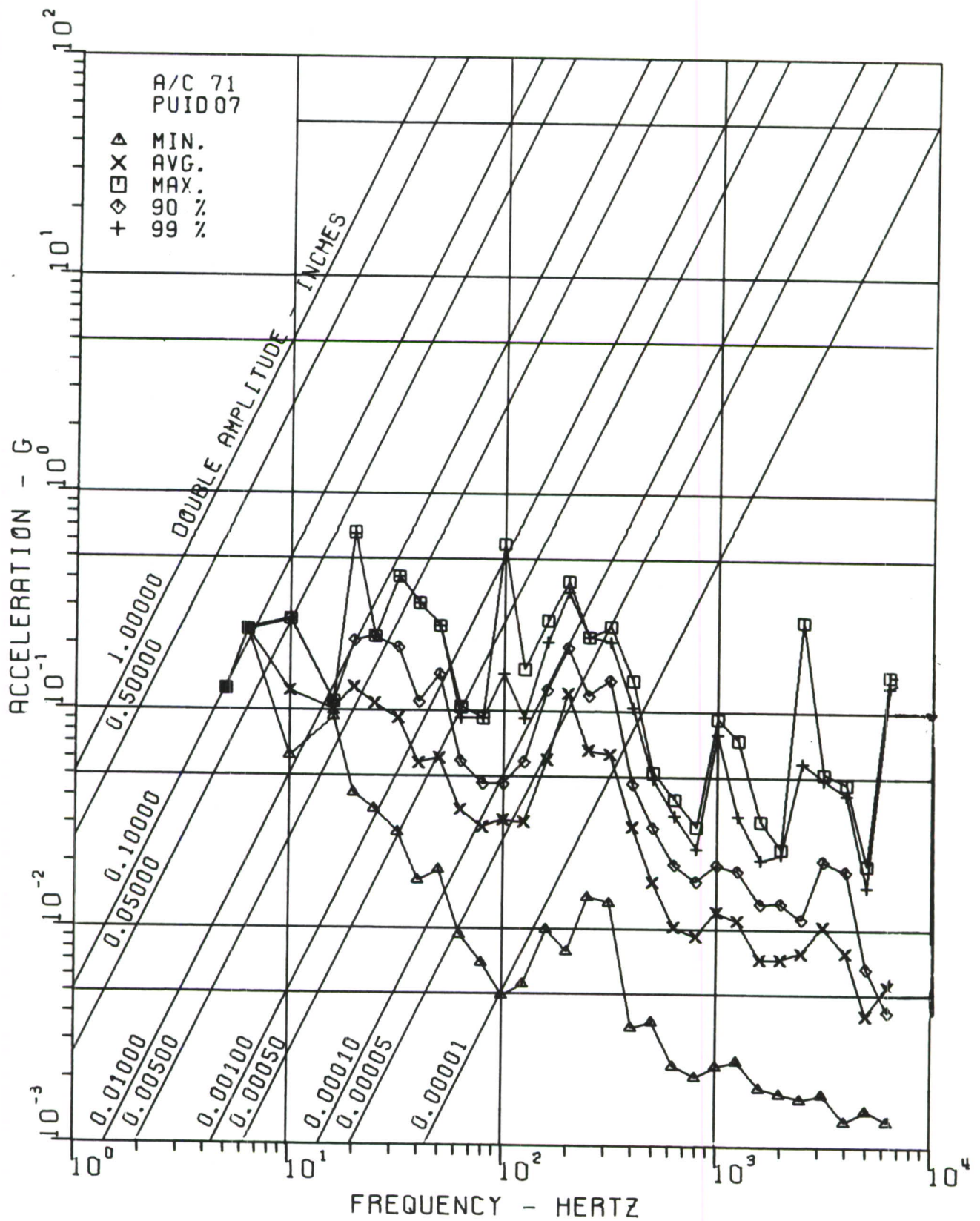


Figure 44 . Gunner's Pedestal, Right Side, Sta. 77, without Gunfire

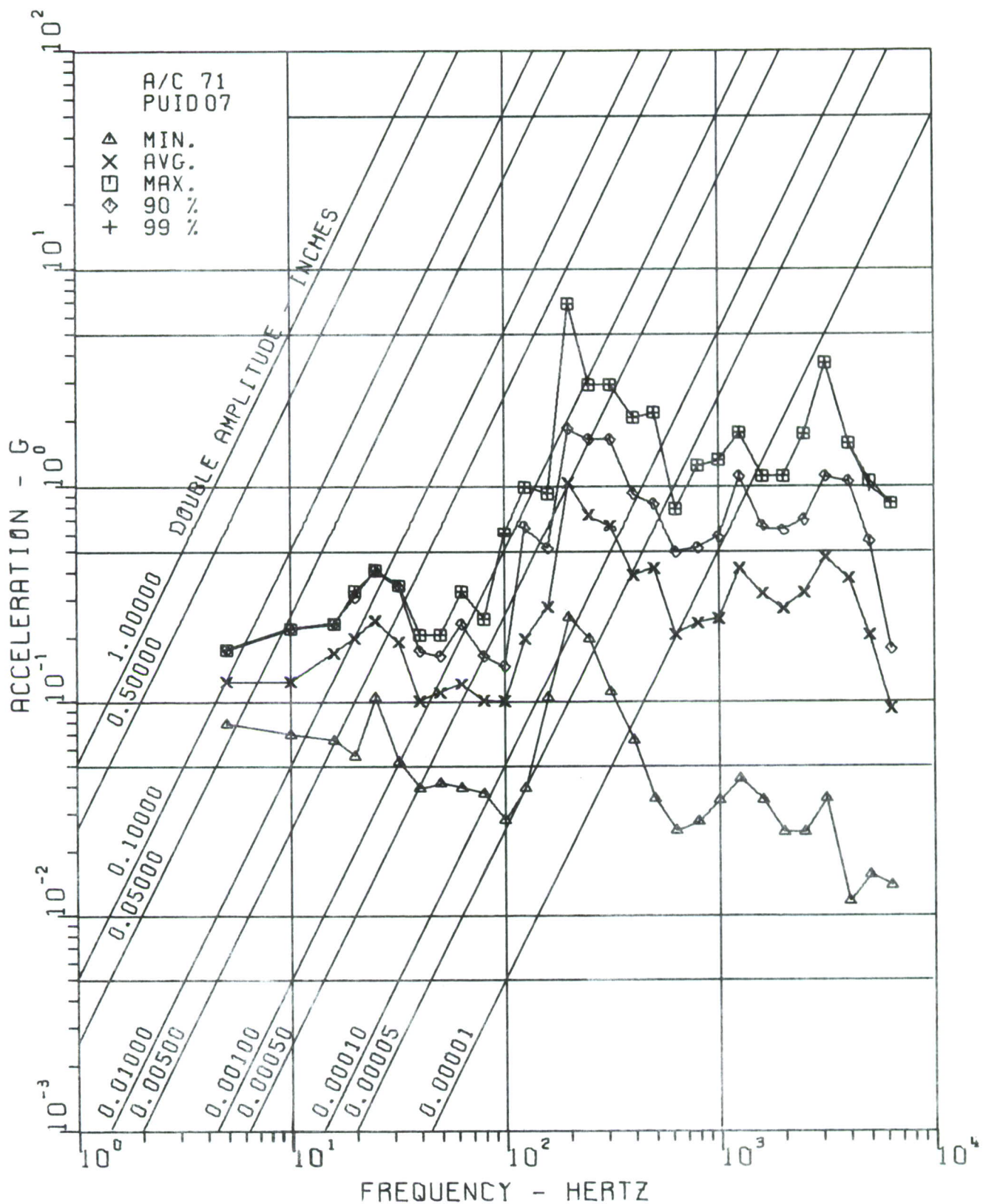


Figure 45. Gunner's Pedestal, Right Side, Sta. 77, with Gunfire

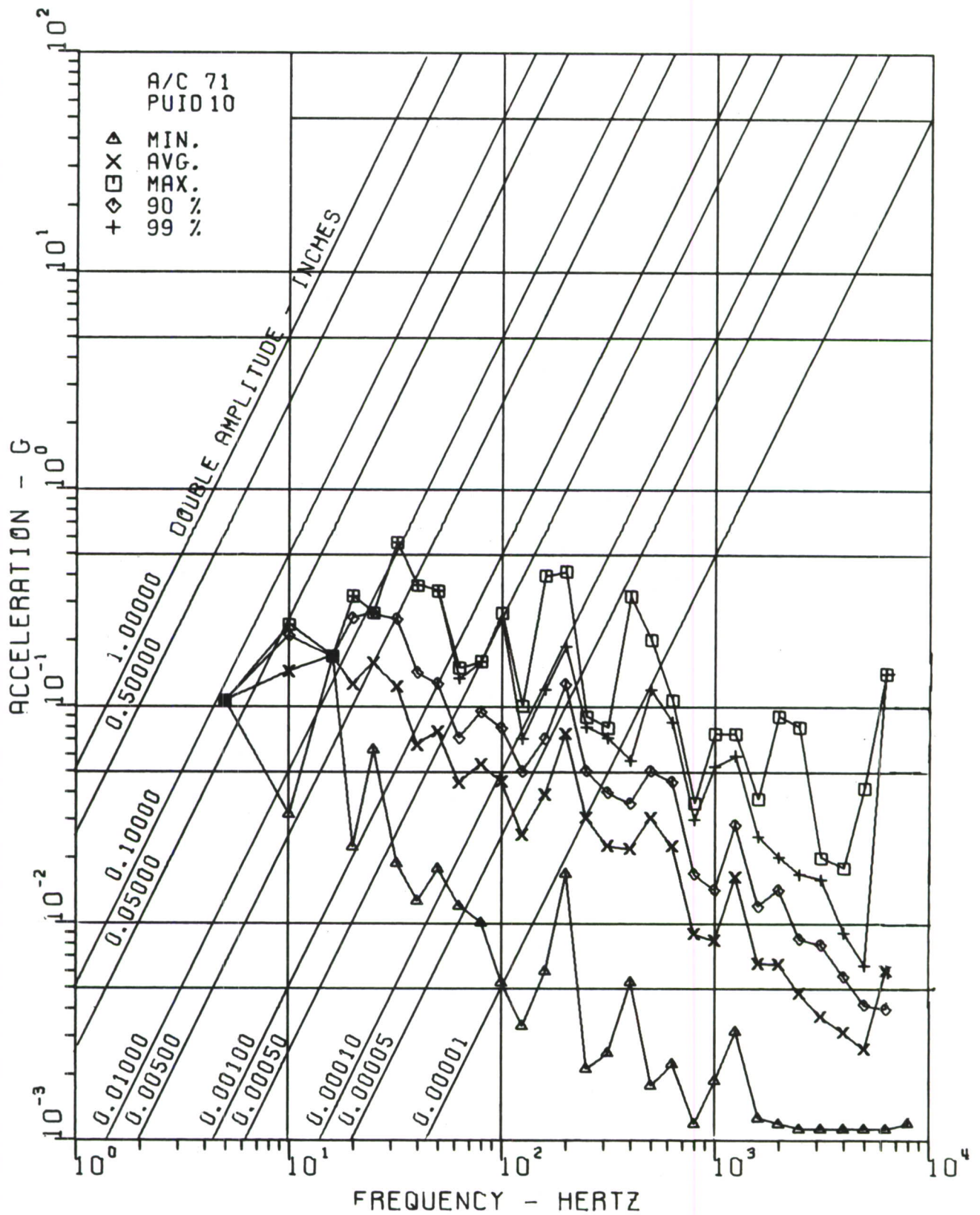


Figure 46. Gunner's Instrument Comp., Right Side, without Gunfire

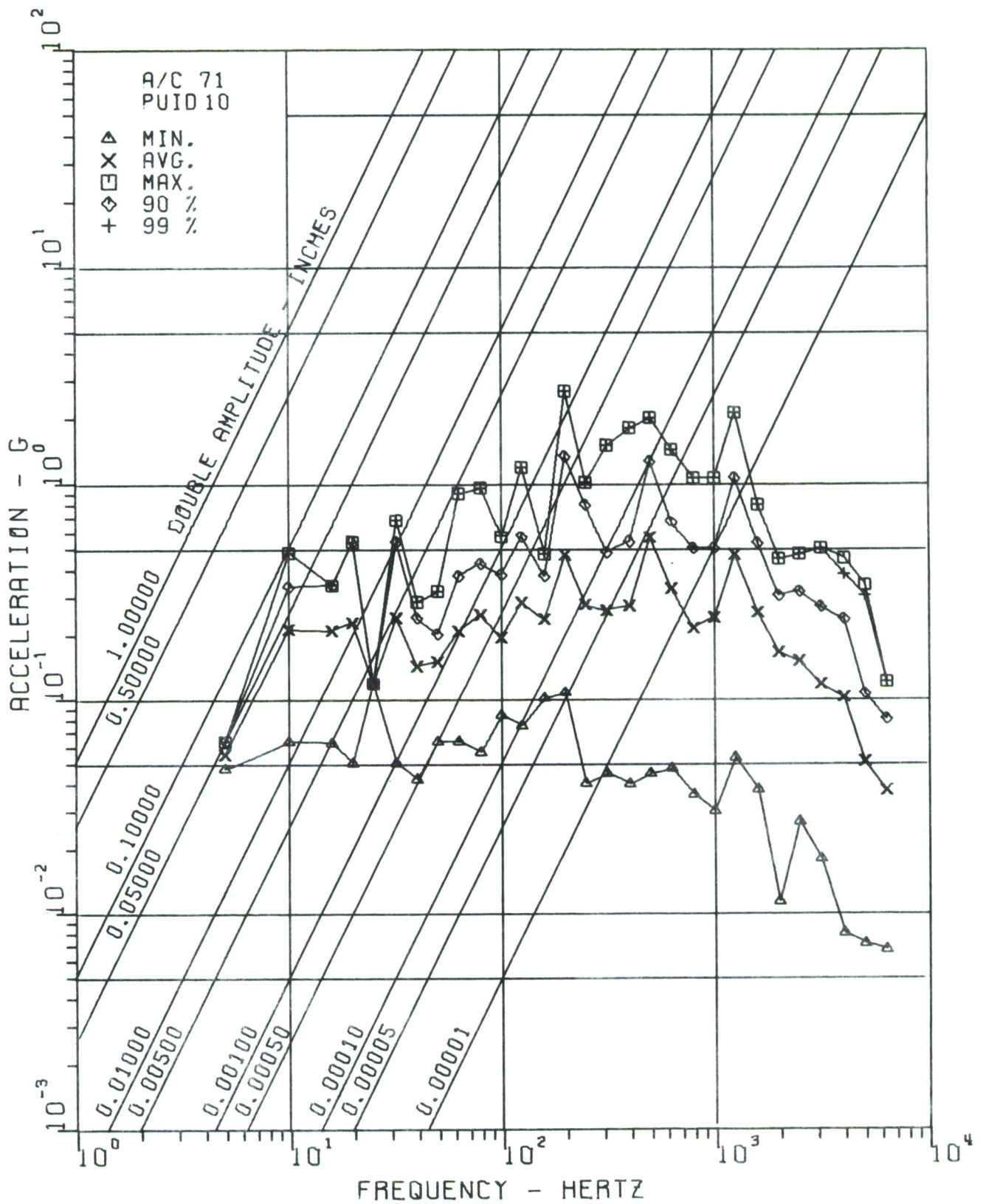


Figure 47. Gunner's Instrument Comp., Right Side, Sta. 73, with Gunfire

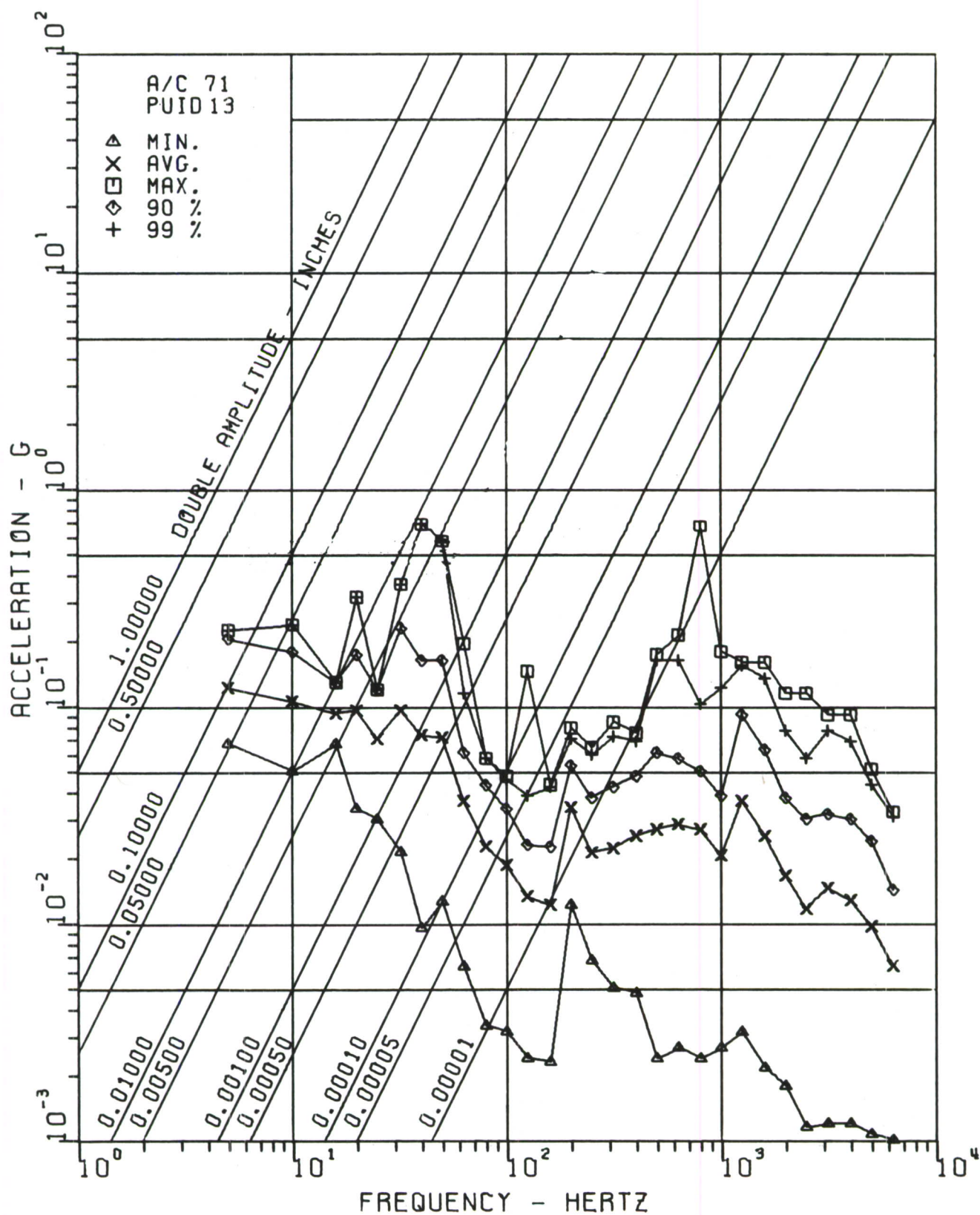


Figure 48. Gunner's Floor, Center, Sta. 66, without Gunfire

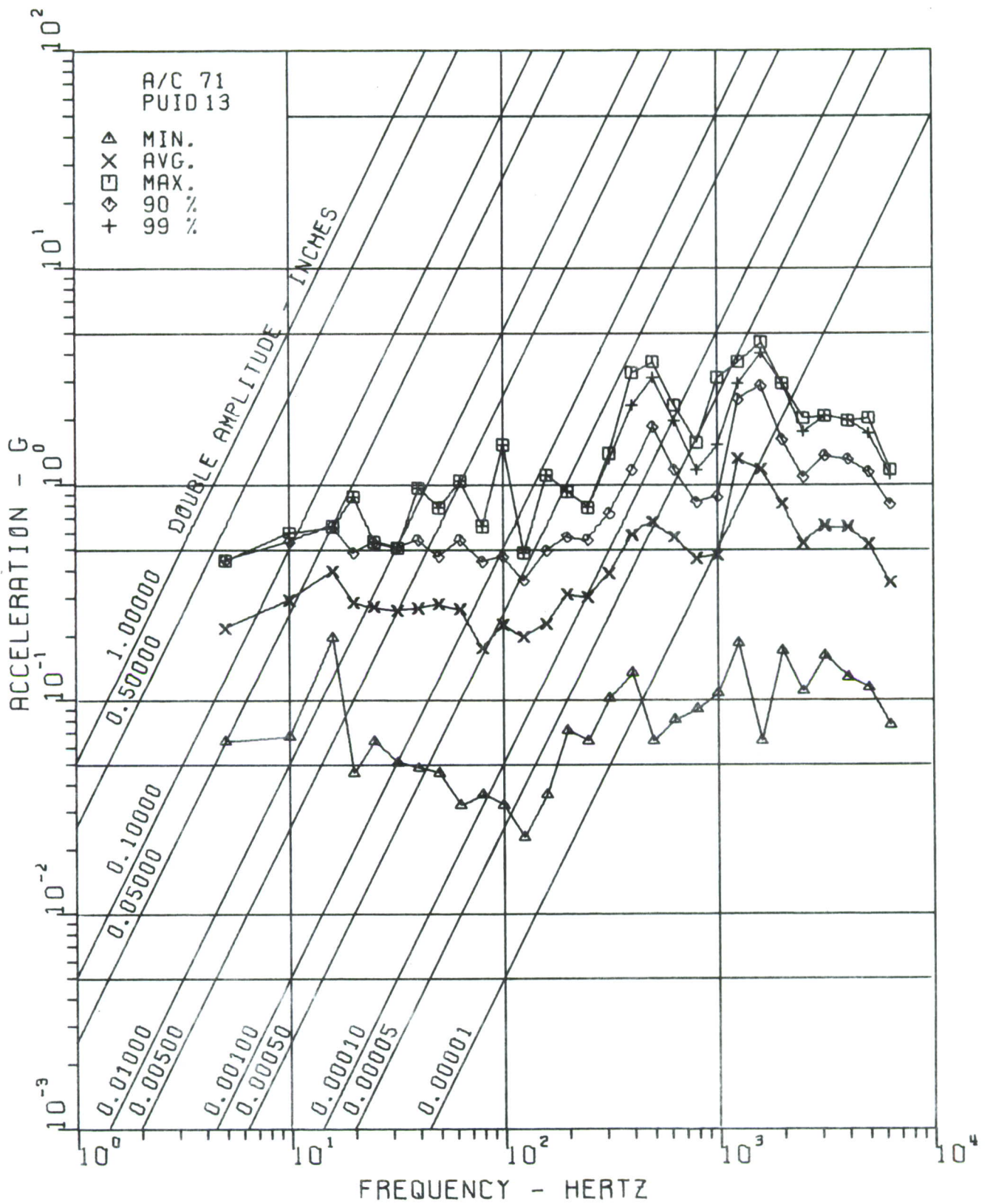


Figure 49. Gunner's Floor, Center, Sta. 66, with Gunfire

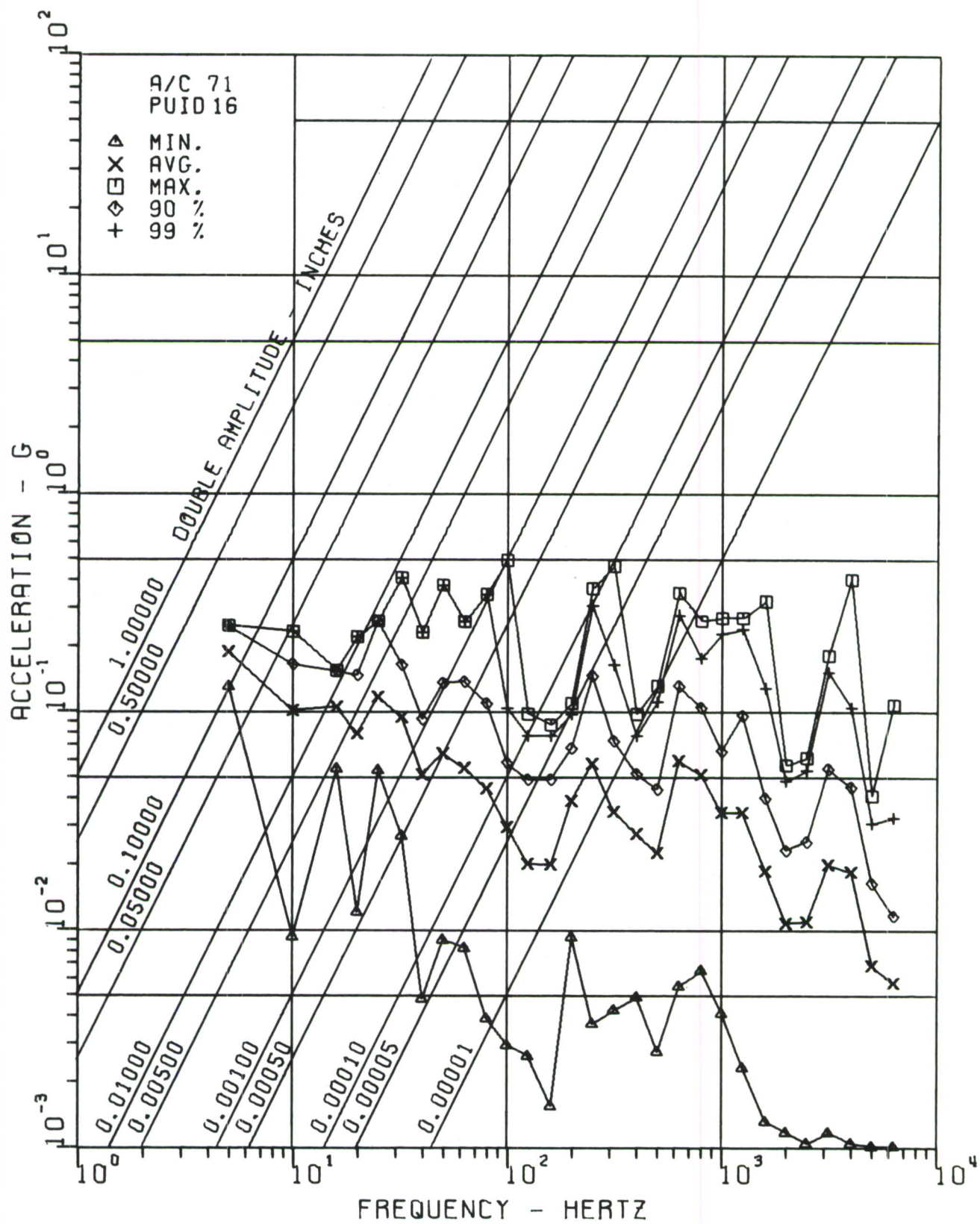


Figure 50. XM-28 Turret Interface, Sta. 69, without Gunfire

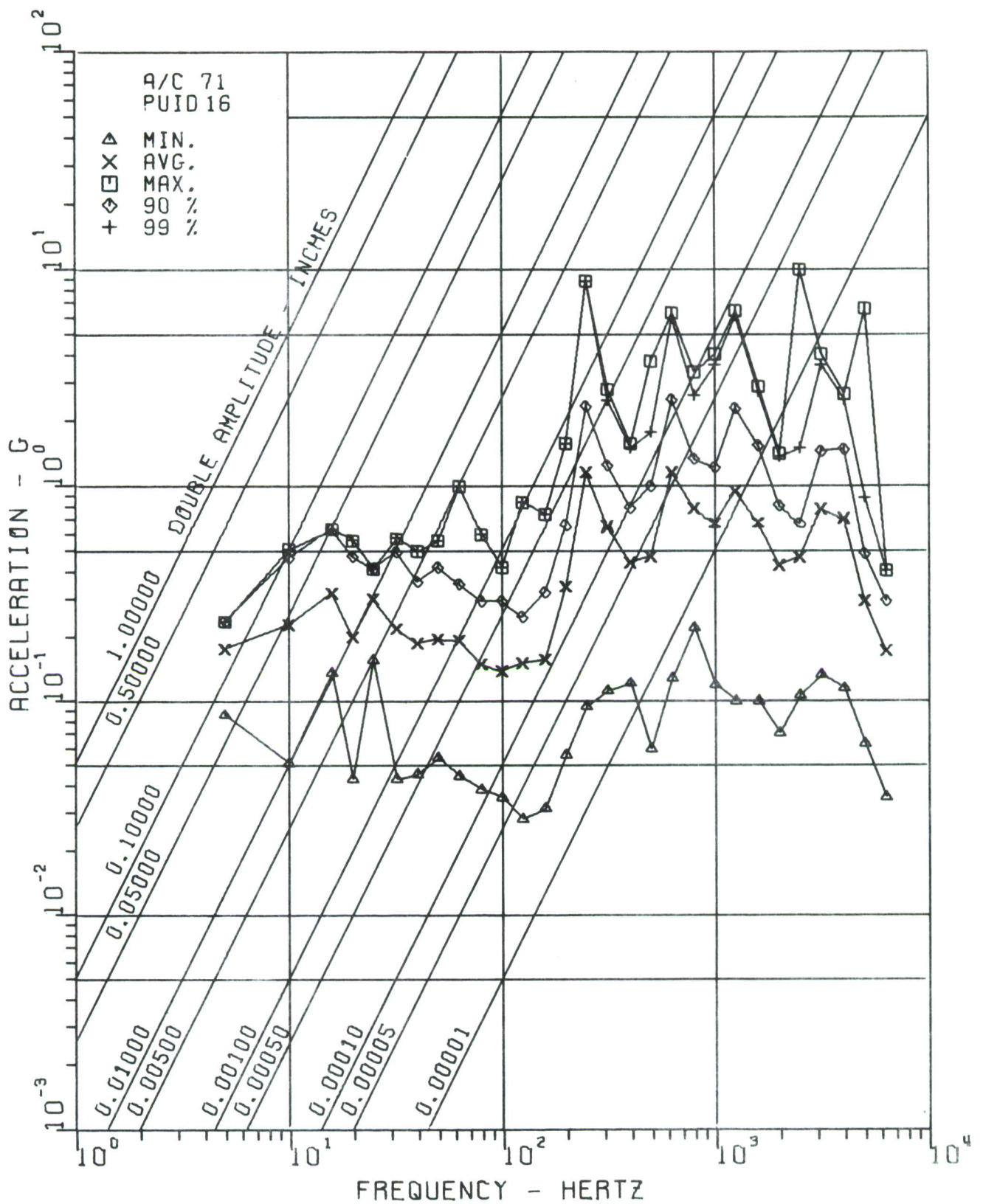


Figure 51. XM-28 Turret Interface, Sta. 69, with Gunfire

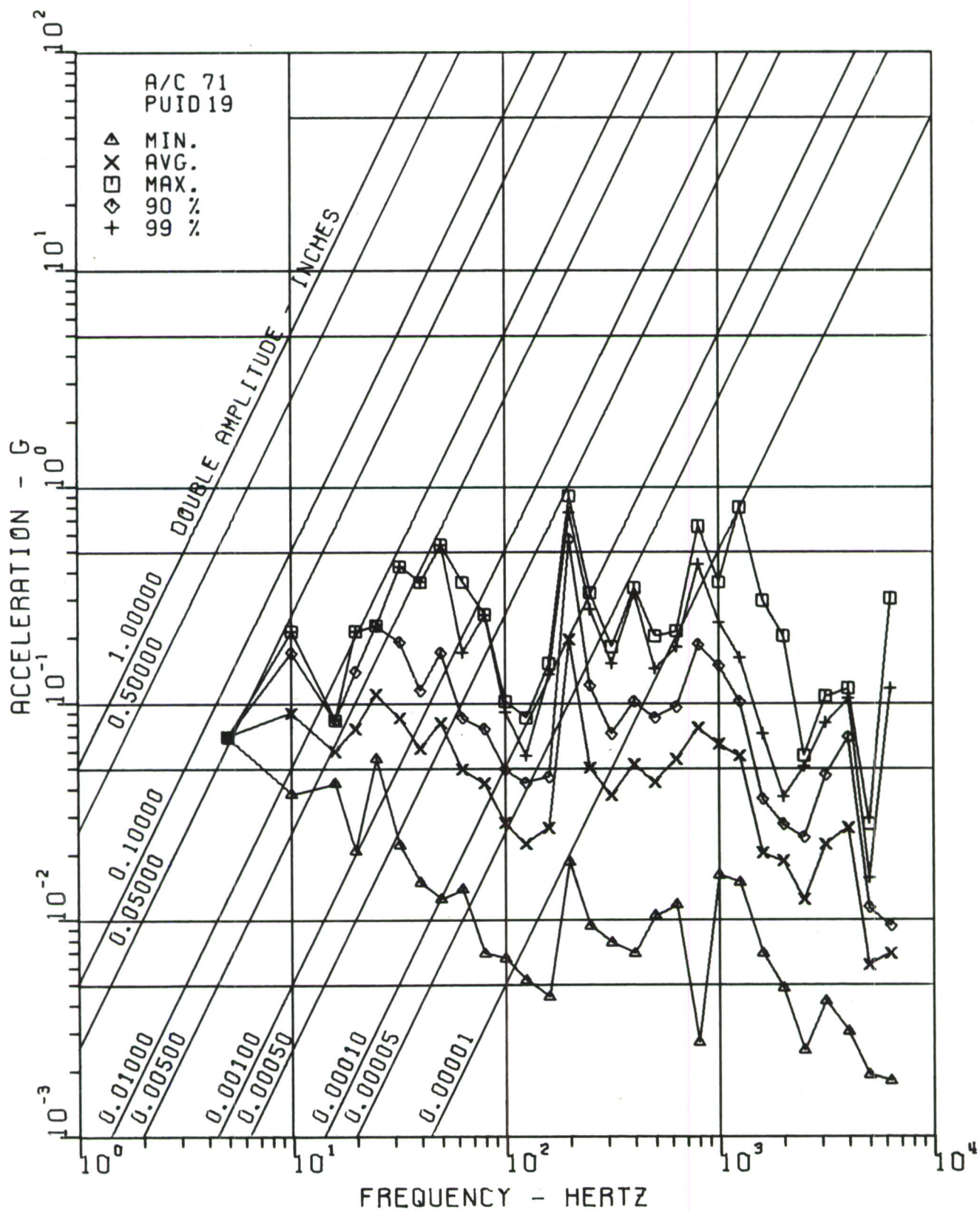


Figure 52. Pilot's Floor, Center, Sta. 134, without Gunfire

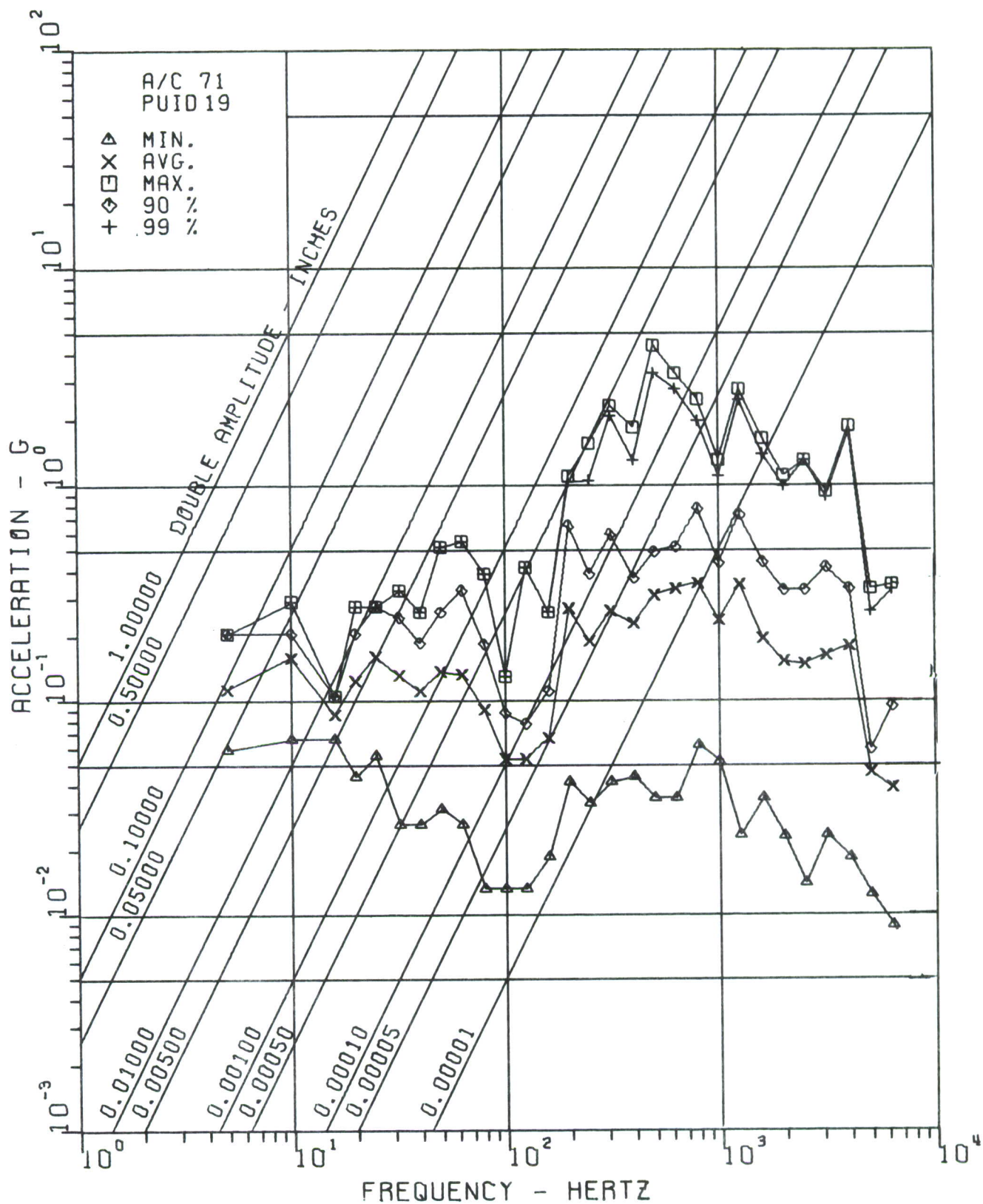


Figure 53. Pilot's Floor, Center, Sta. 134, with Gunfire

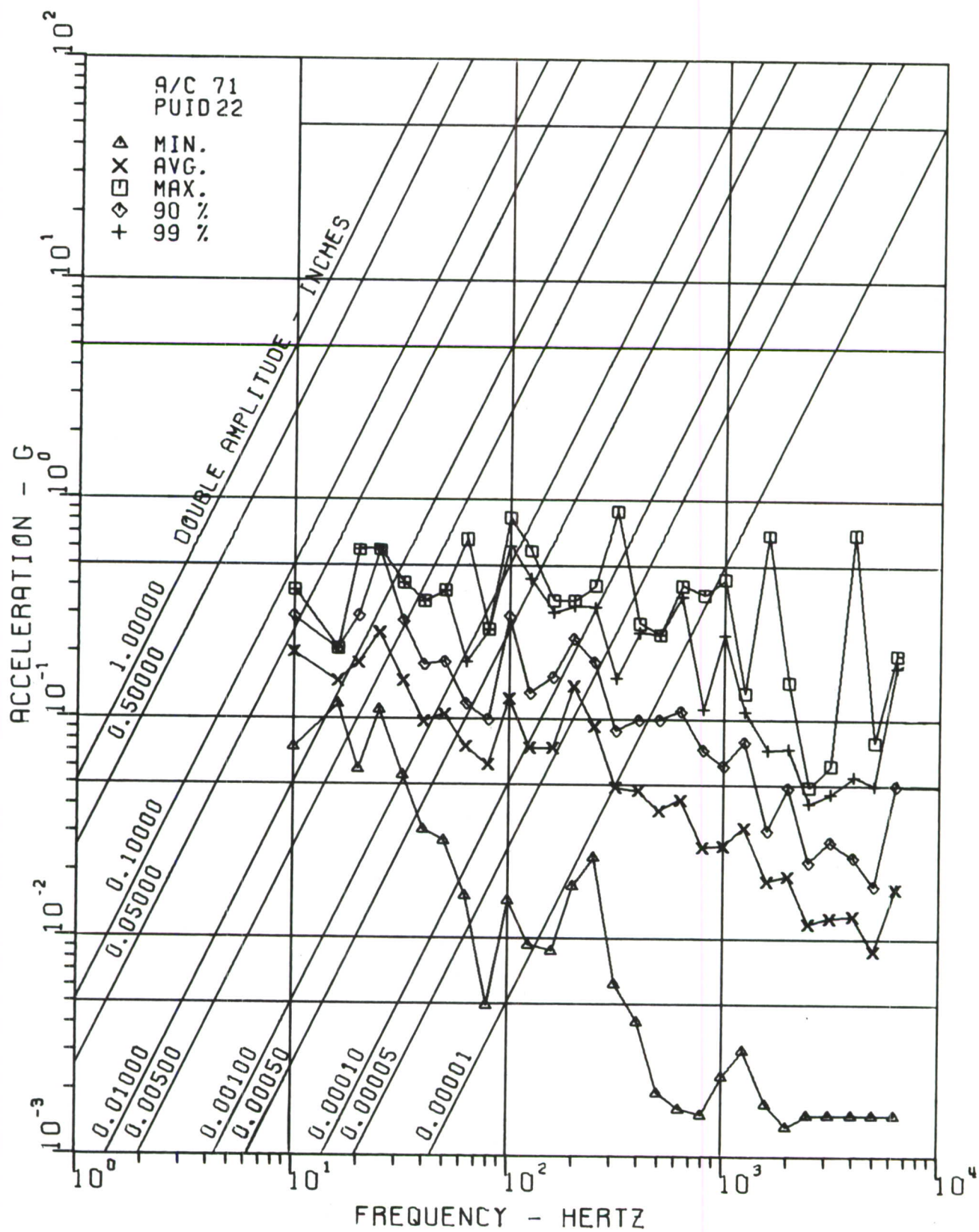


Figure 54. XM-28 Turret, Center, Sta. 77, without Gunfire

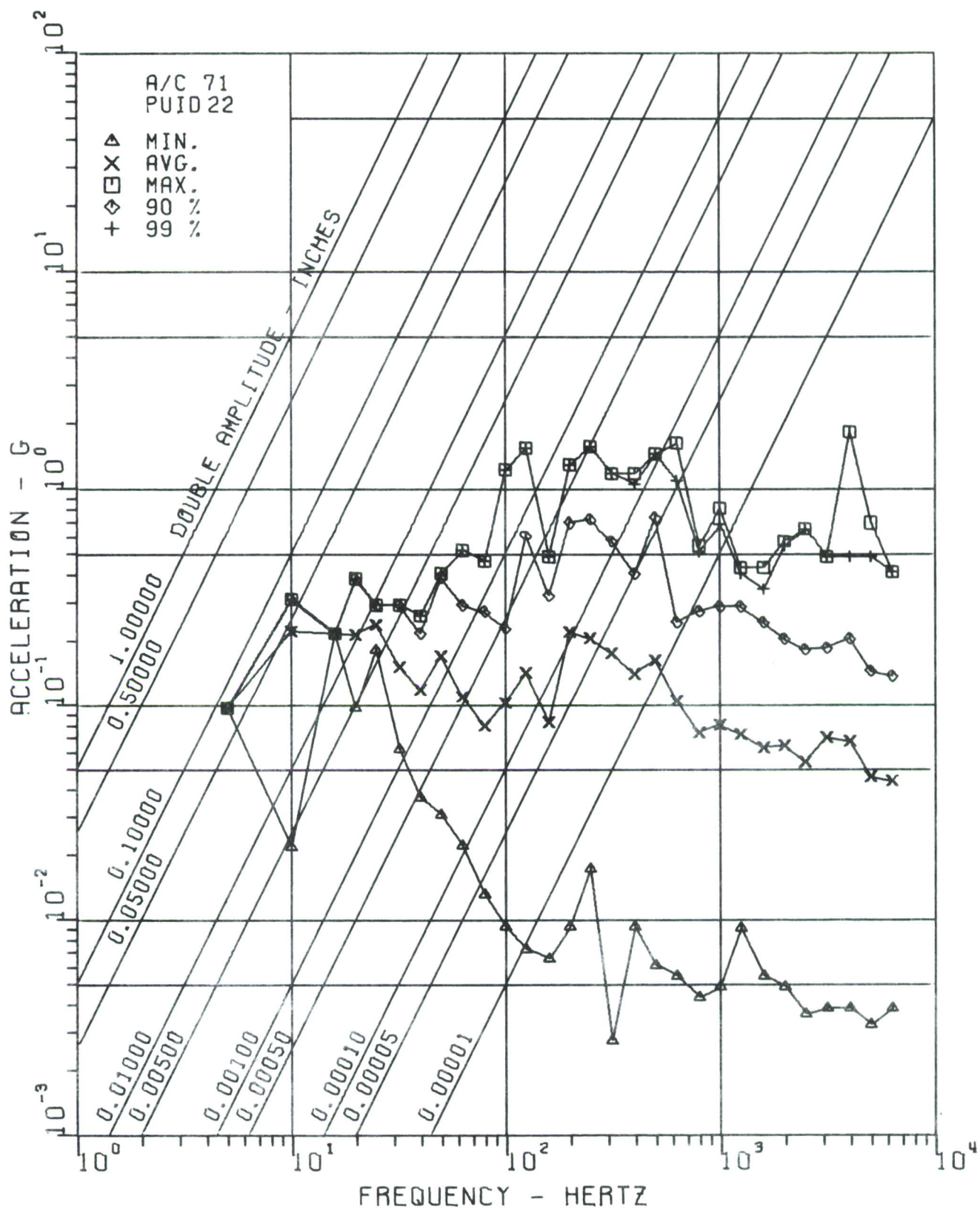


Figure 55. XM-28 Turret, Center, Sta. 77, with Gunfire

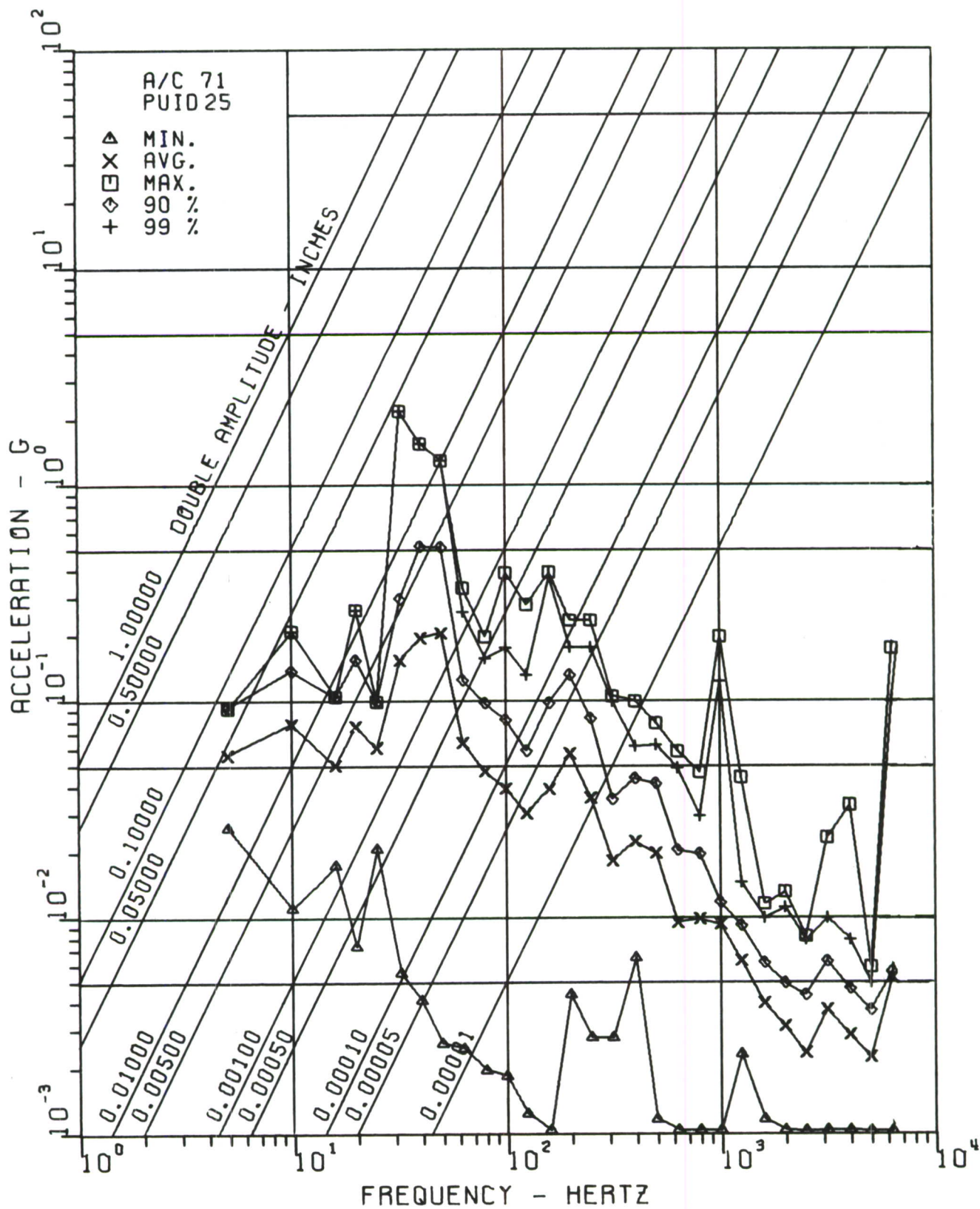


Figure 56. Pilot's Instrument Panel, Right Side, Sta. 115, without Gunfire

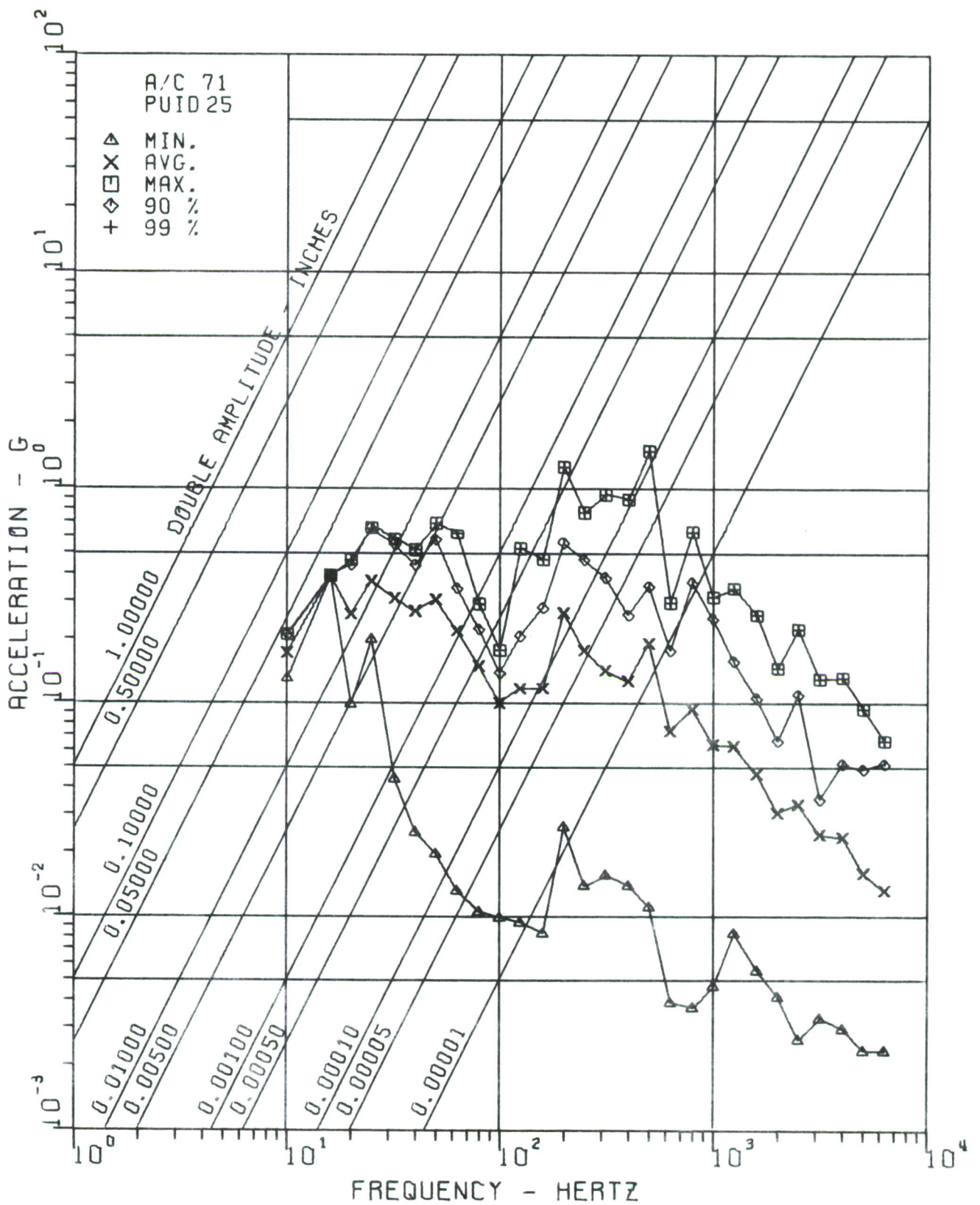


Figure 57. Pilot's Instrument Panel, Right Side, Sta. 115, with Gunfire

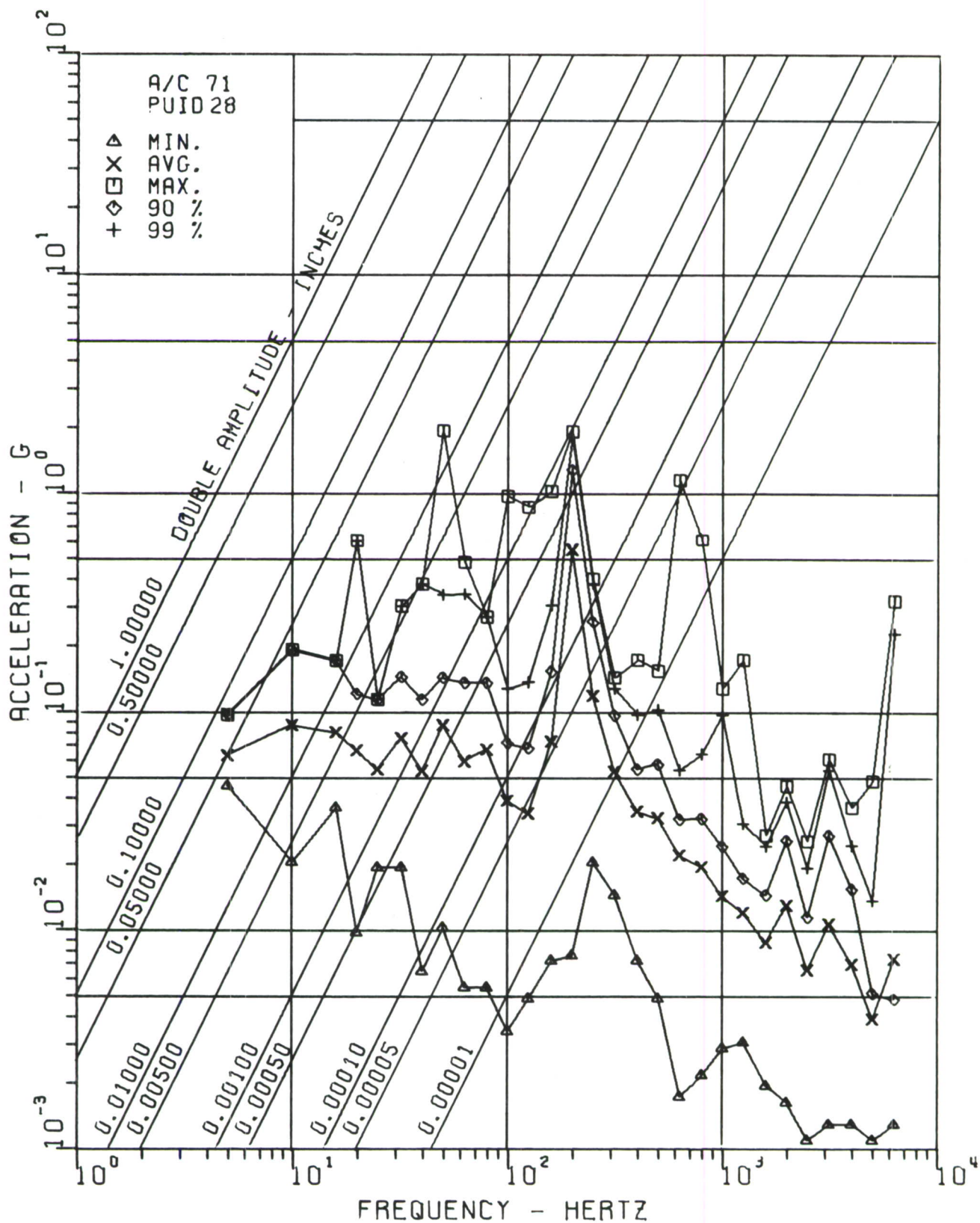


Figure 58. Pilot's Pedestal, Left Side, Sta. 122, without Gunfire

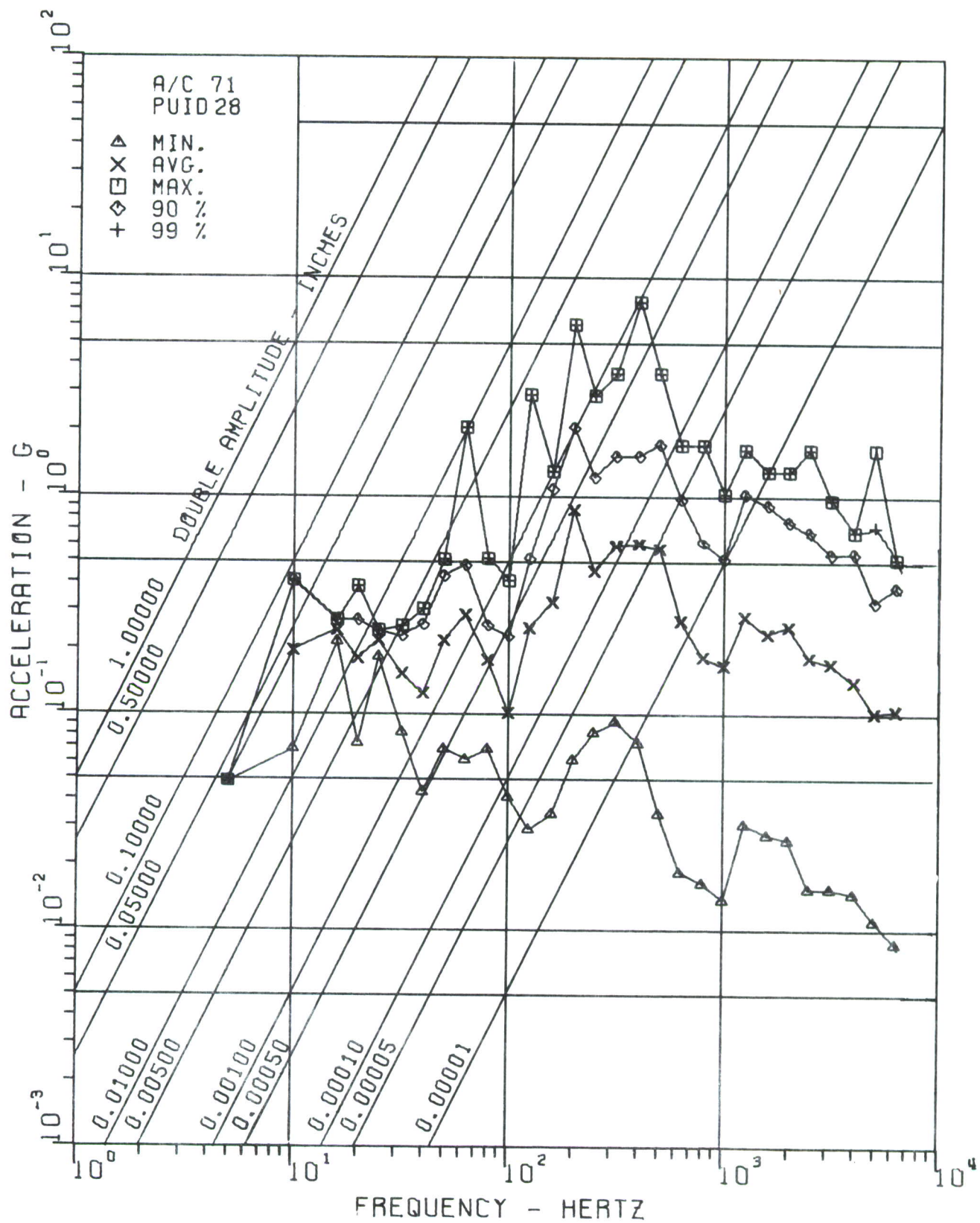


Figure 59. Pilot's Pedestal, Left Side, Sta. 122, with Gunfire

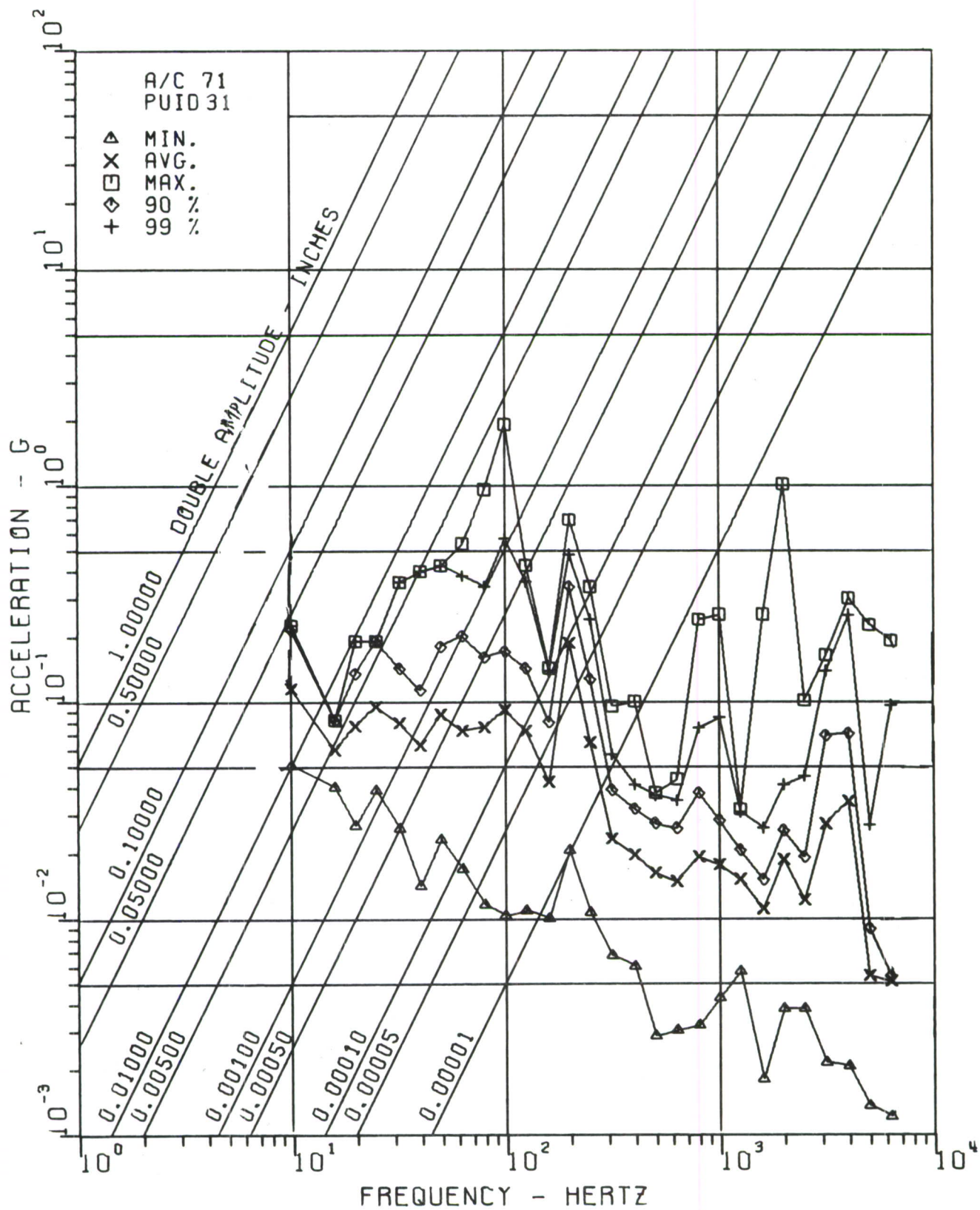


Figure 60. Pilot's Instrument Comp., Left Side, Sta. 122, without Gunfire

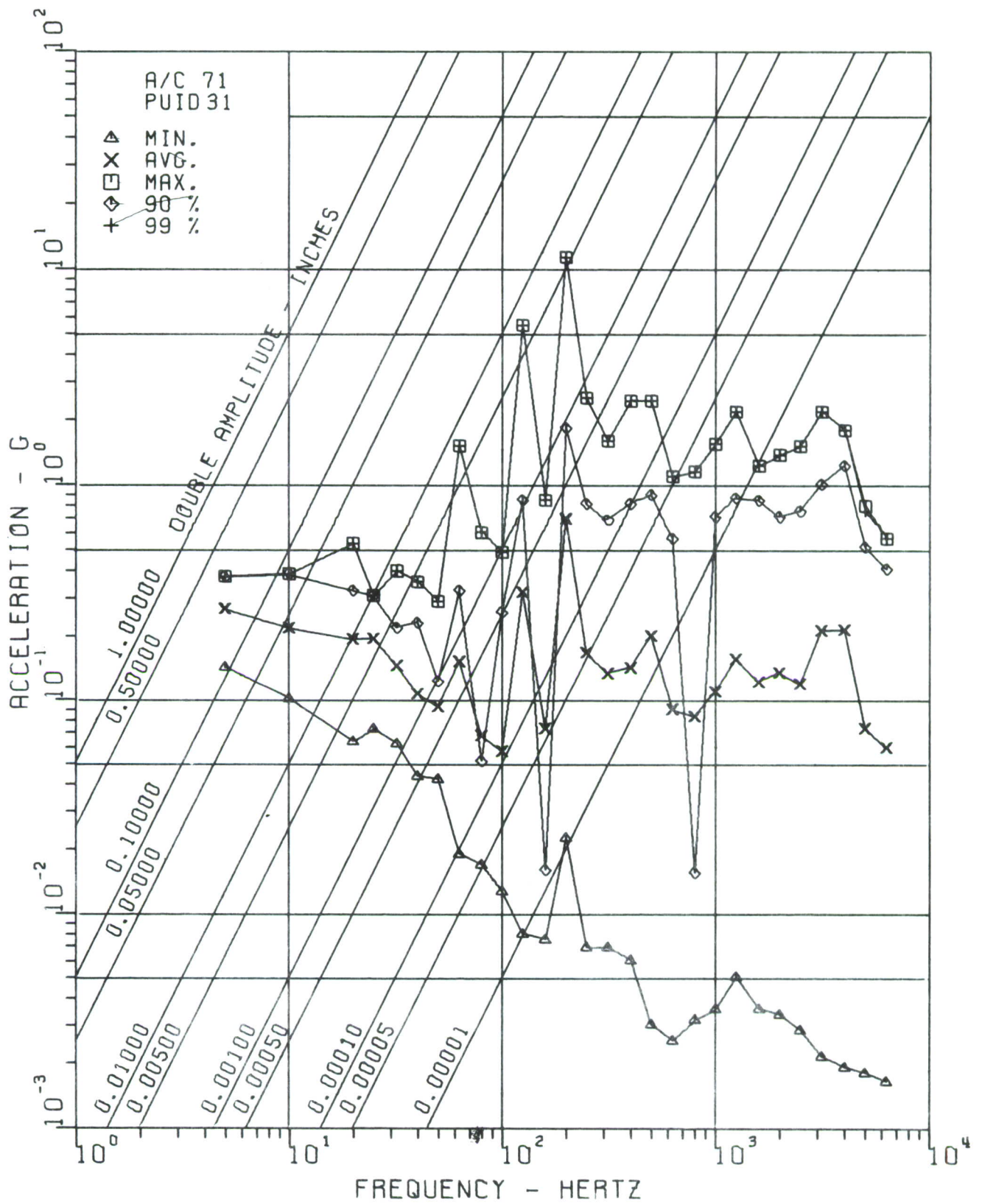


Figure 61. Pilot's Instrument Comp., Left Side, Sta. 122, with Gunfire

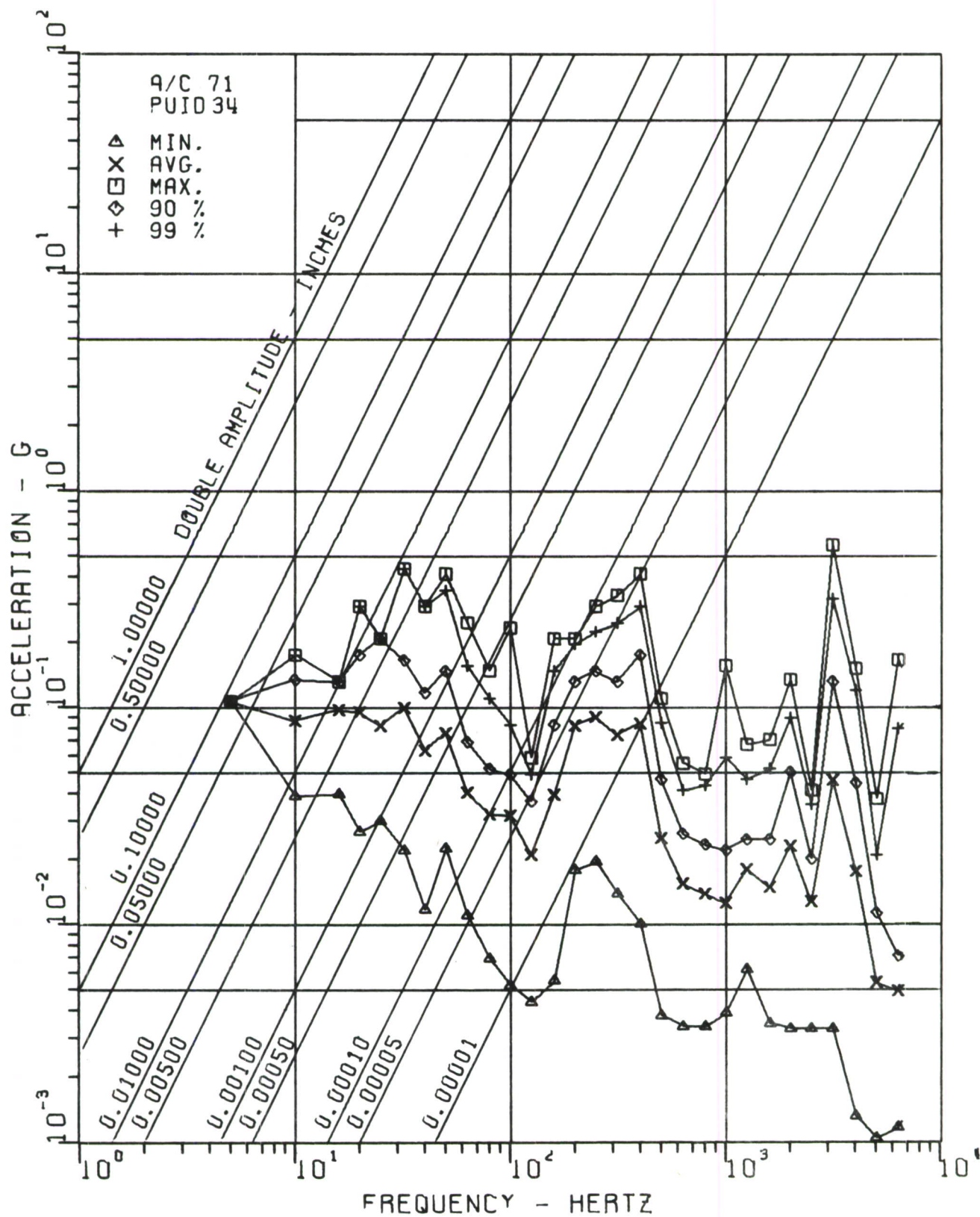


Figure 62. Pilot's Instrument Comp., Right Side, Sta. 130, without Gunfire

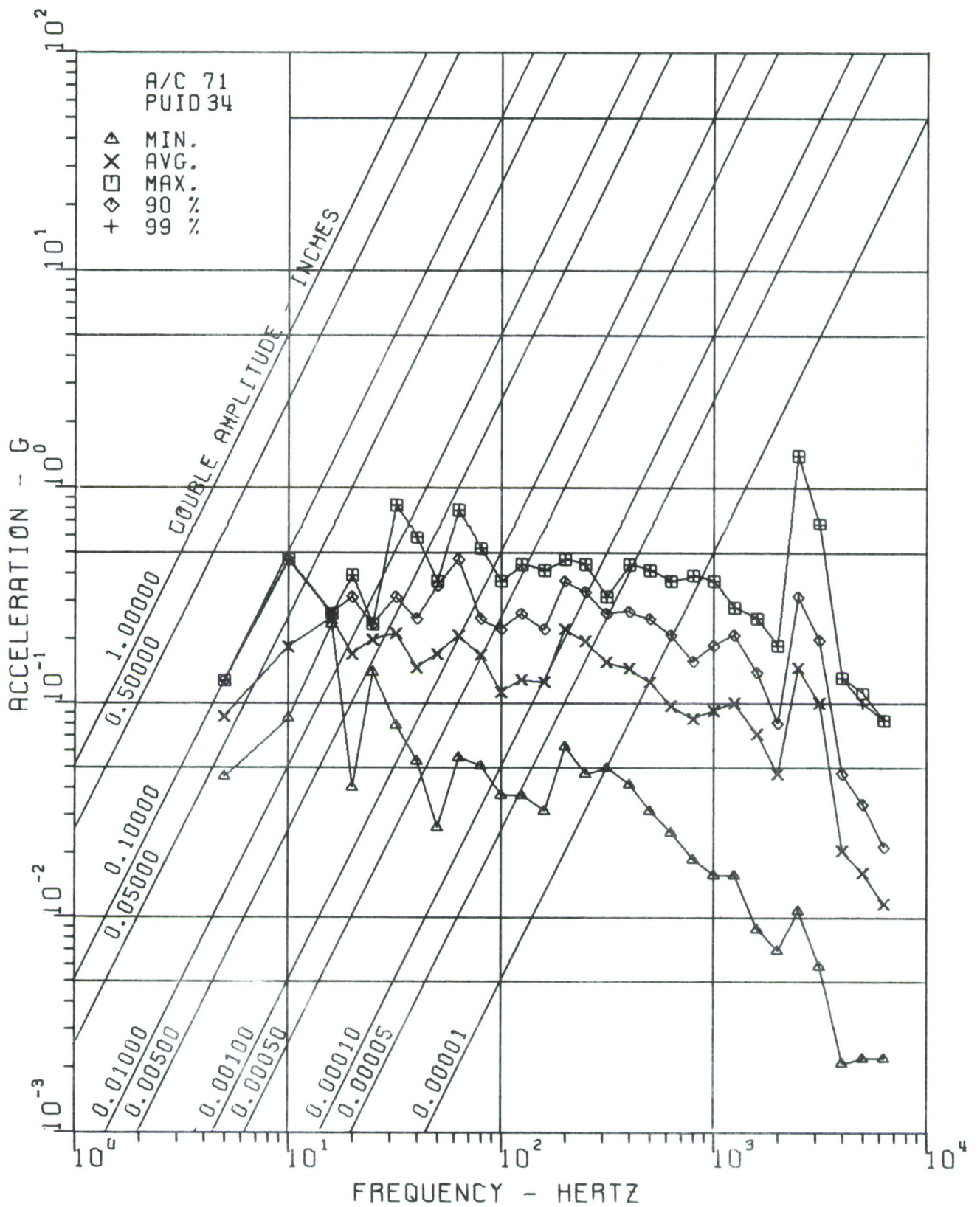


Figure 63. Pilot's Instrument Comp., Right Side, Sta. 130, with Gunfire

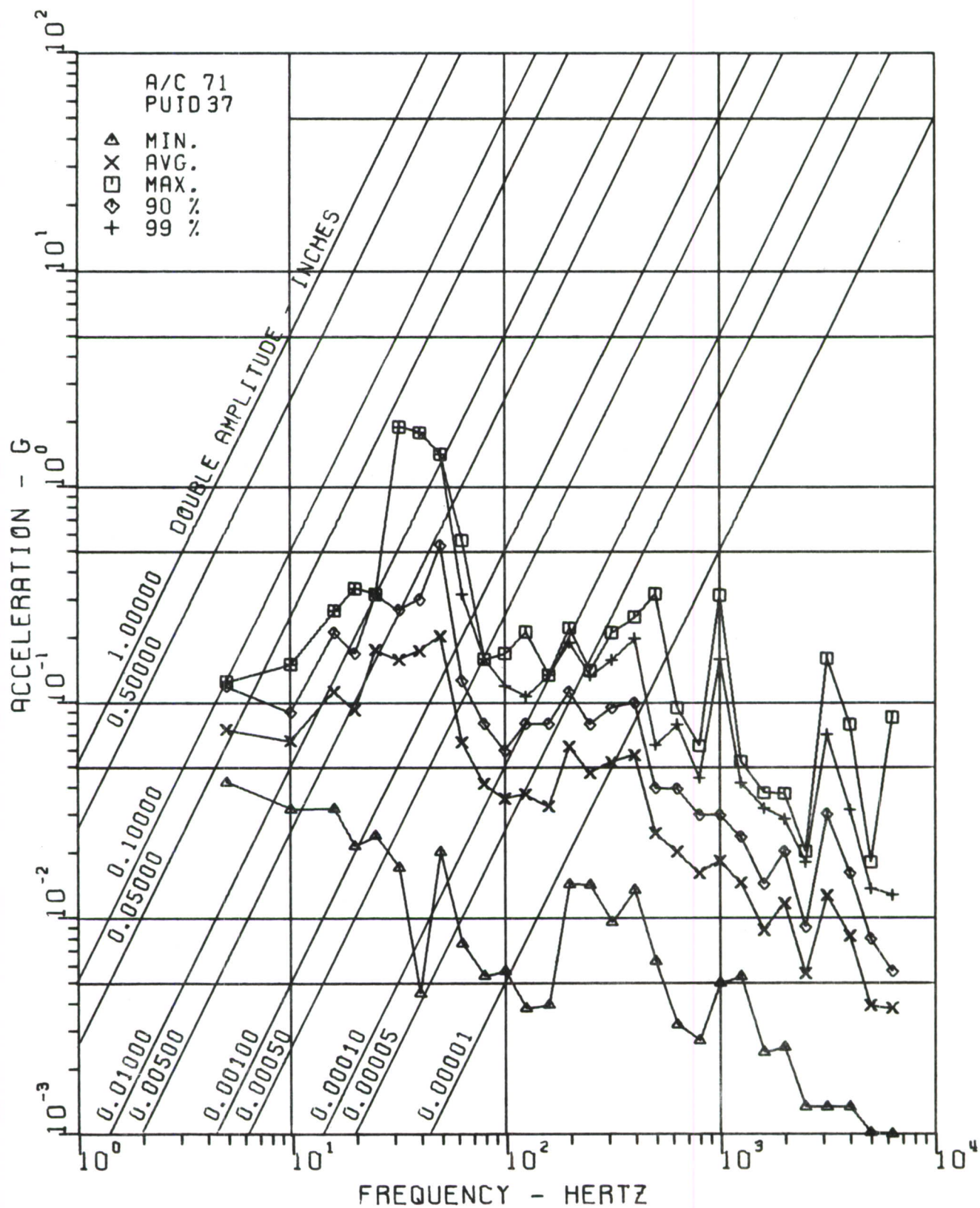


Figure 64. Pilot's Pedestal, Right Side, Sta. 136, without Gunfire

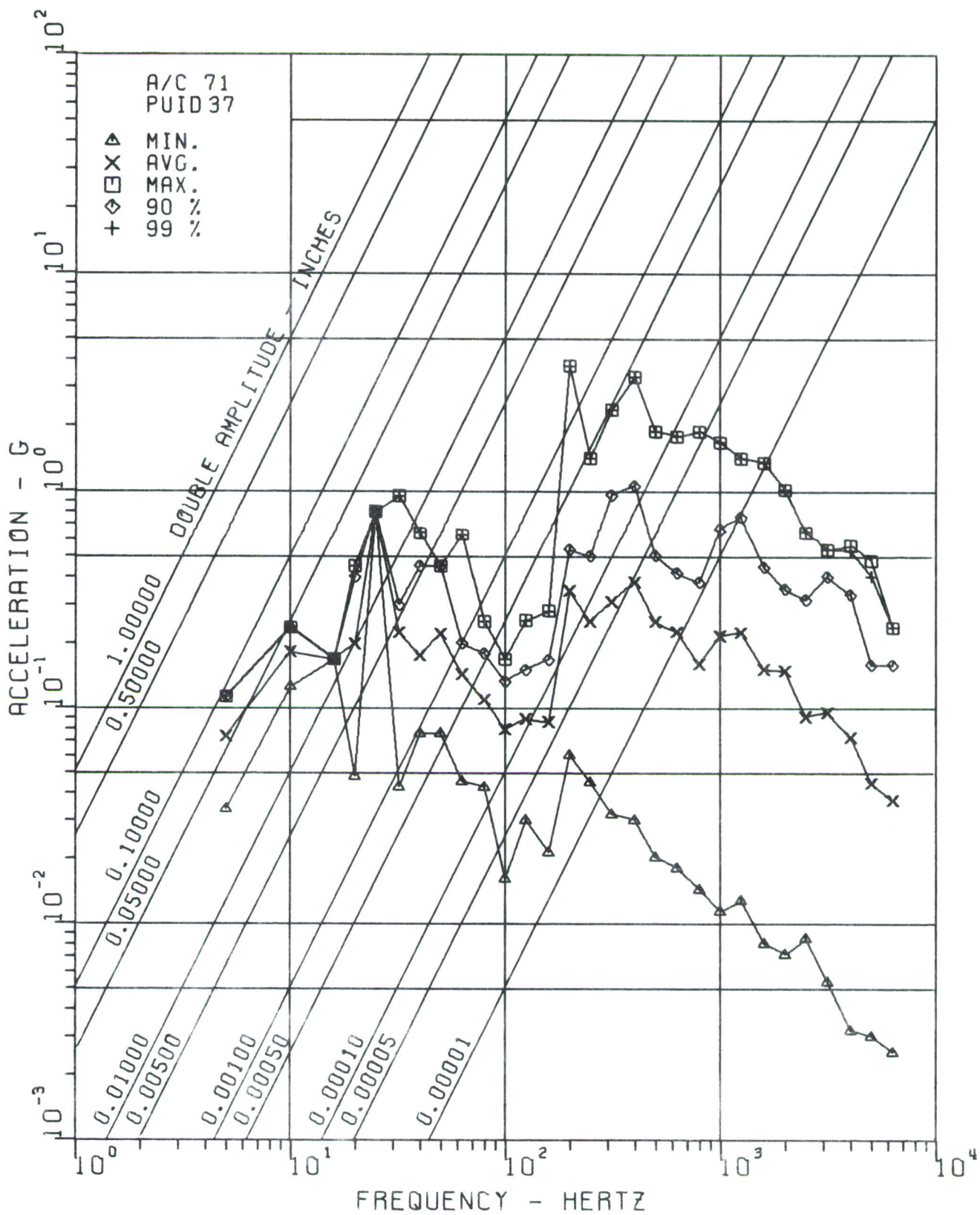


Figure 65. Pilot's Pedestal, Right Side, Sta. 136, with Gunfire

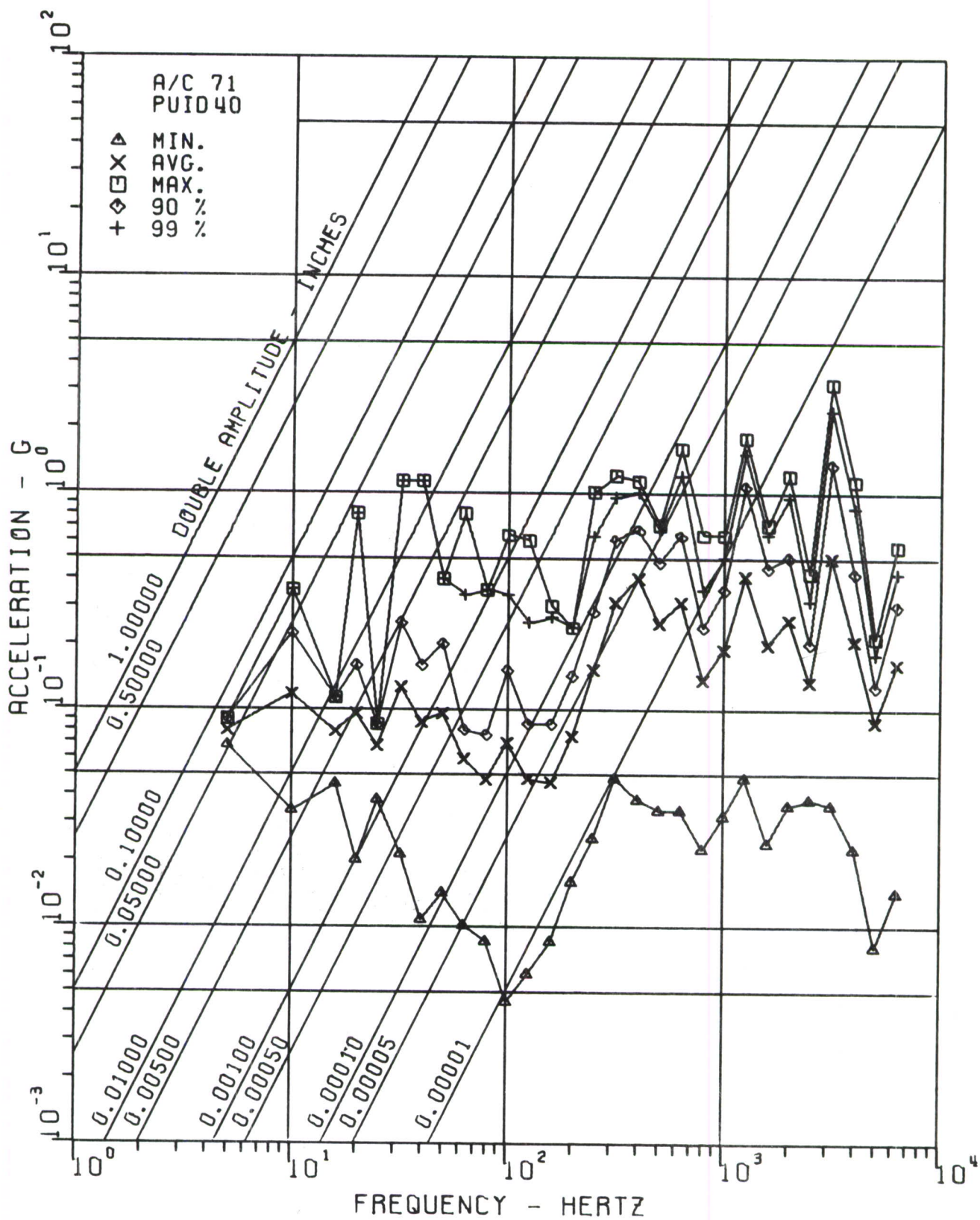


Figure 66. Main Transmission Mount, Left Front, Sta. 188, without Gunfire

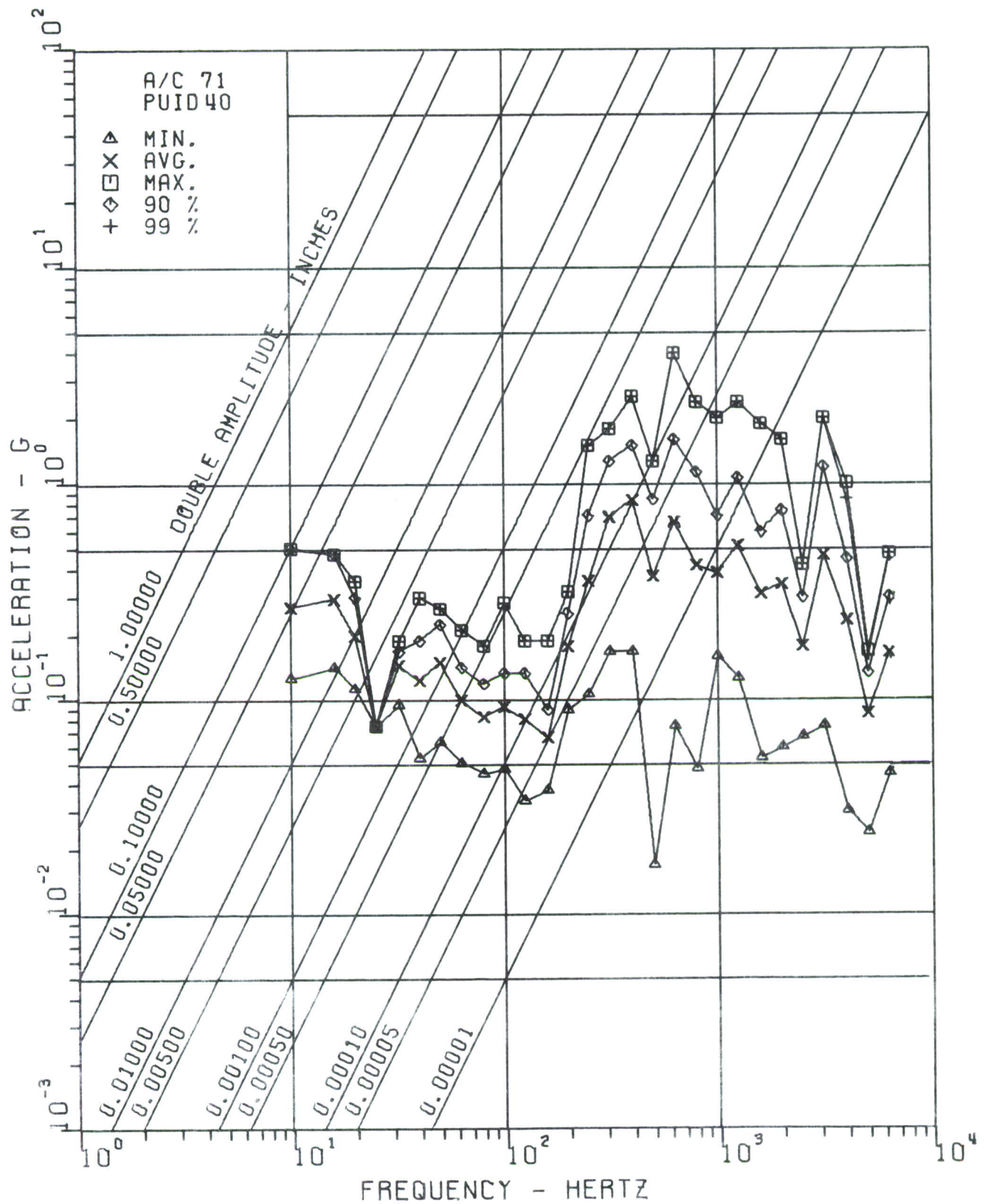


Figure 67. Main Transmission Mount, Left Front, Sta. 188, with Gunfire

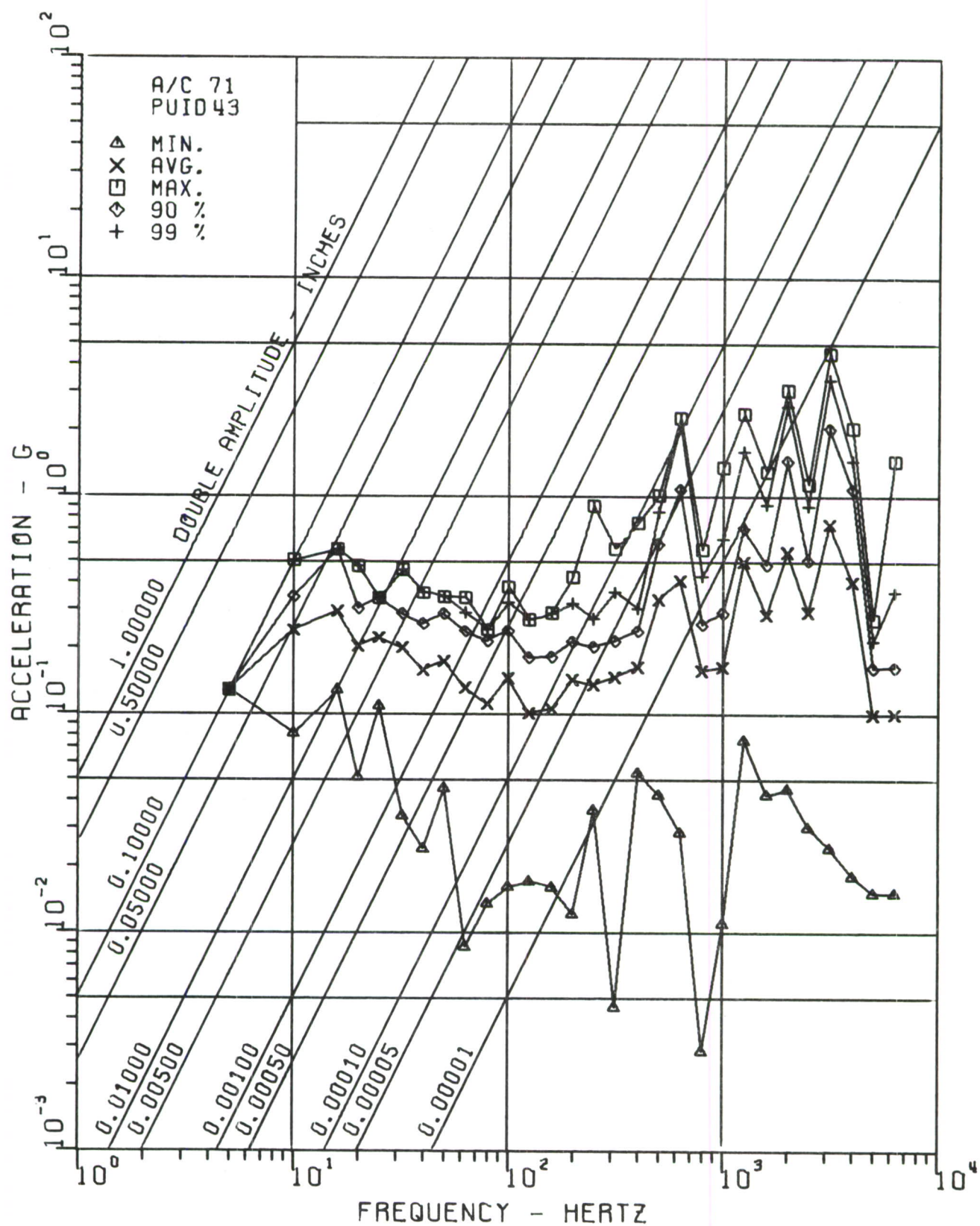


Figure 68. Main Transmission Mount, Right Rear, Sta. 202, without Gunfire

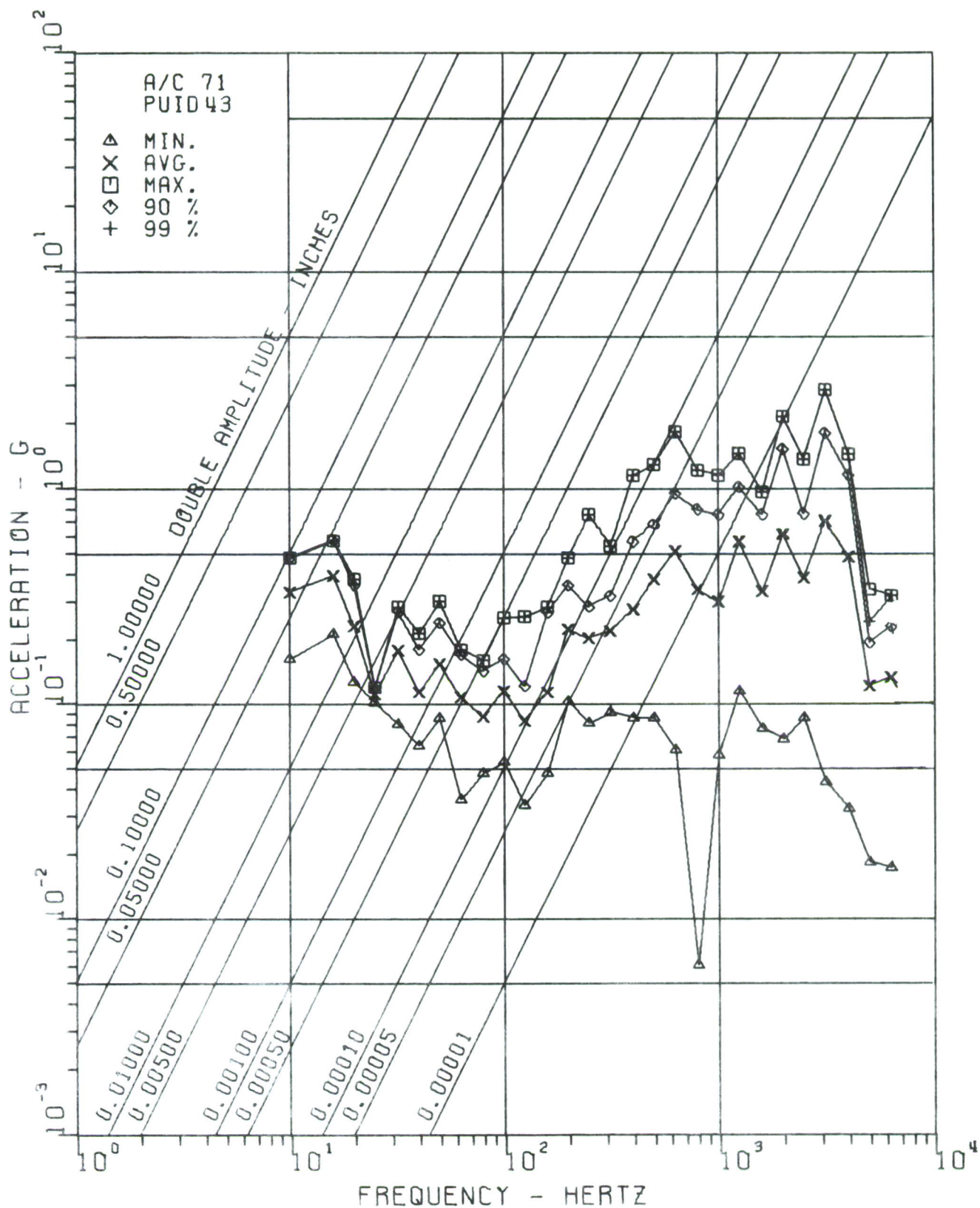


Figure 69. Main Transmission Mount, Right Rear, Sta. 202, with Gunfire

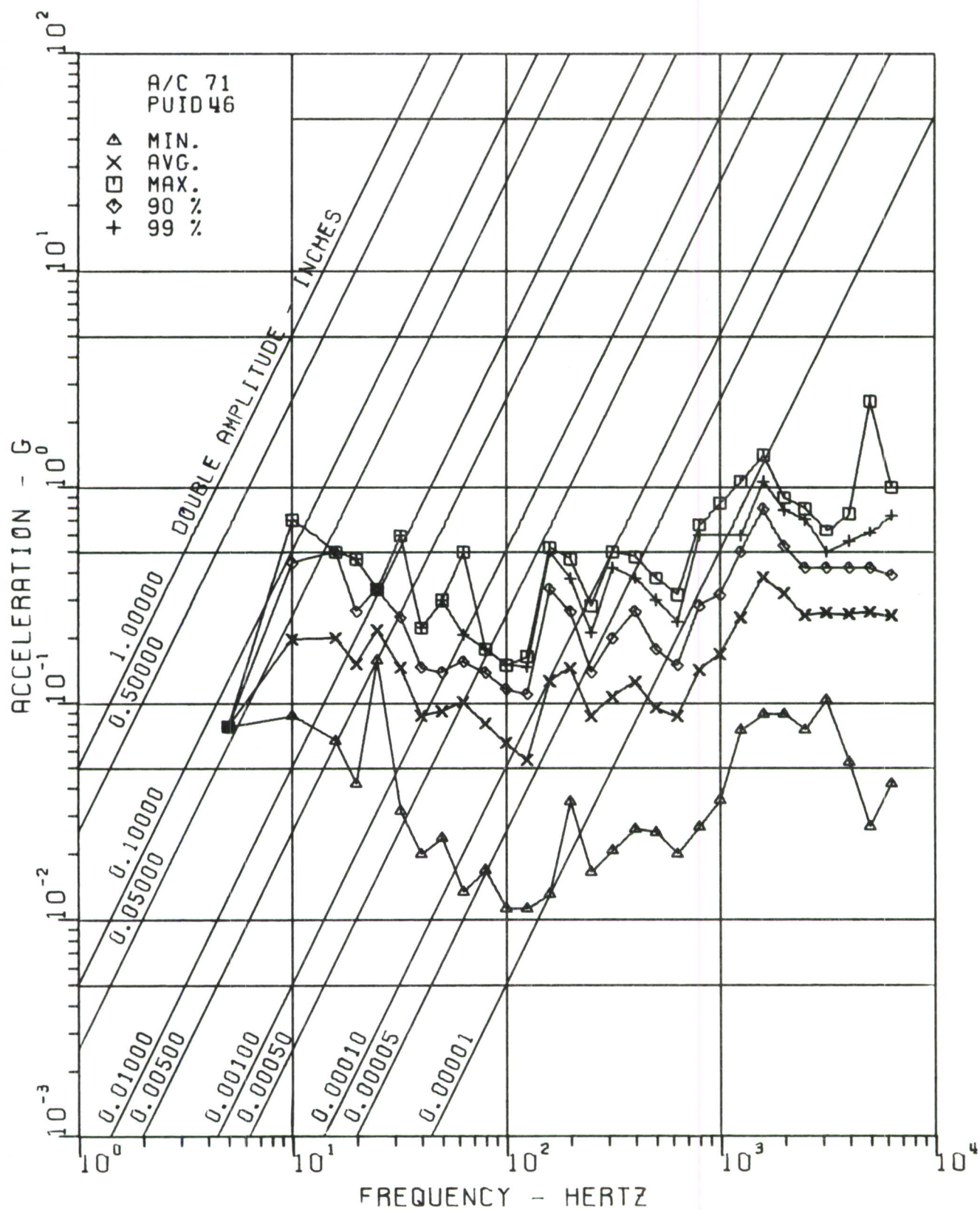


Figure 70. Engine Mount, Left Side, Sta. 244, without Gunfire

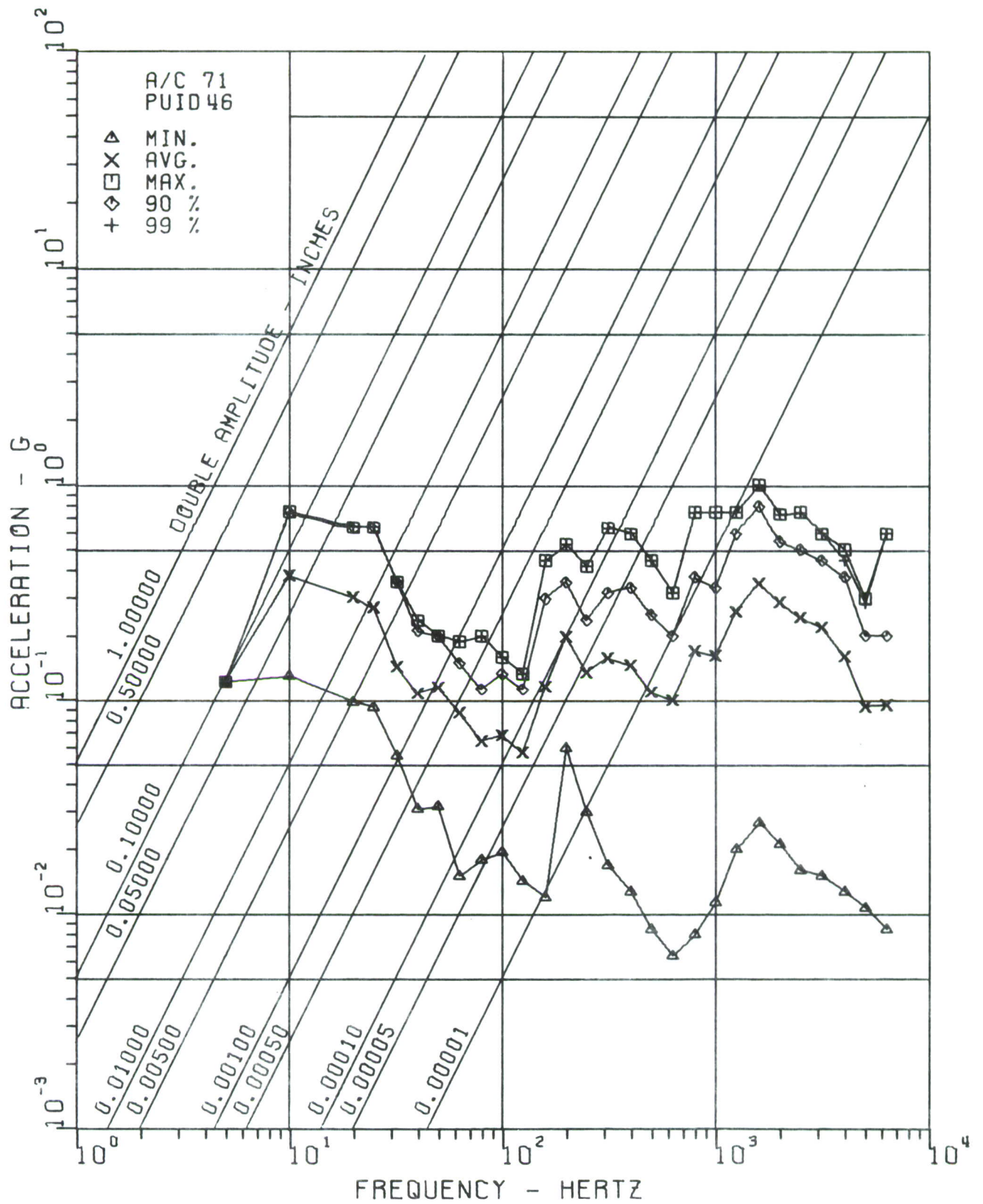


Figure 71. Engine Mount, Left Side, Sta. 244, with Gunfire

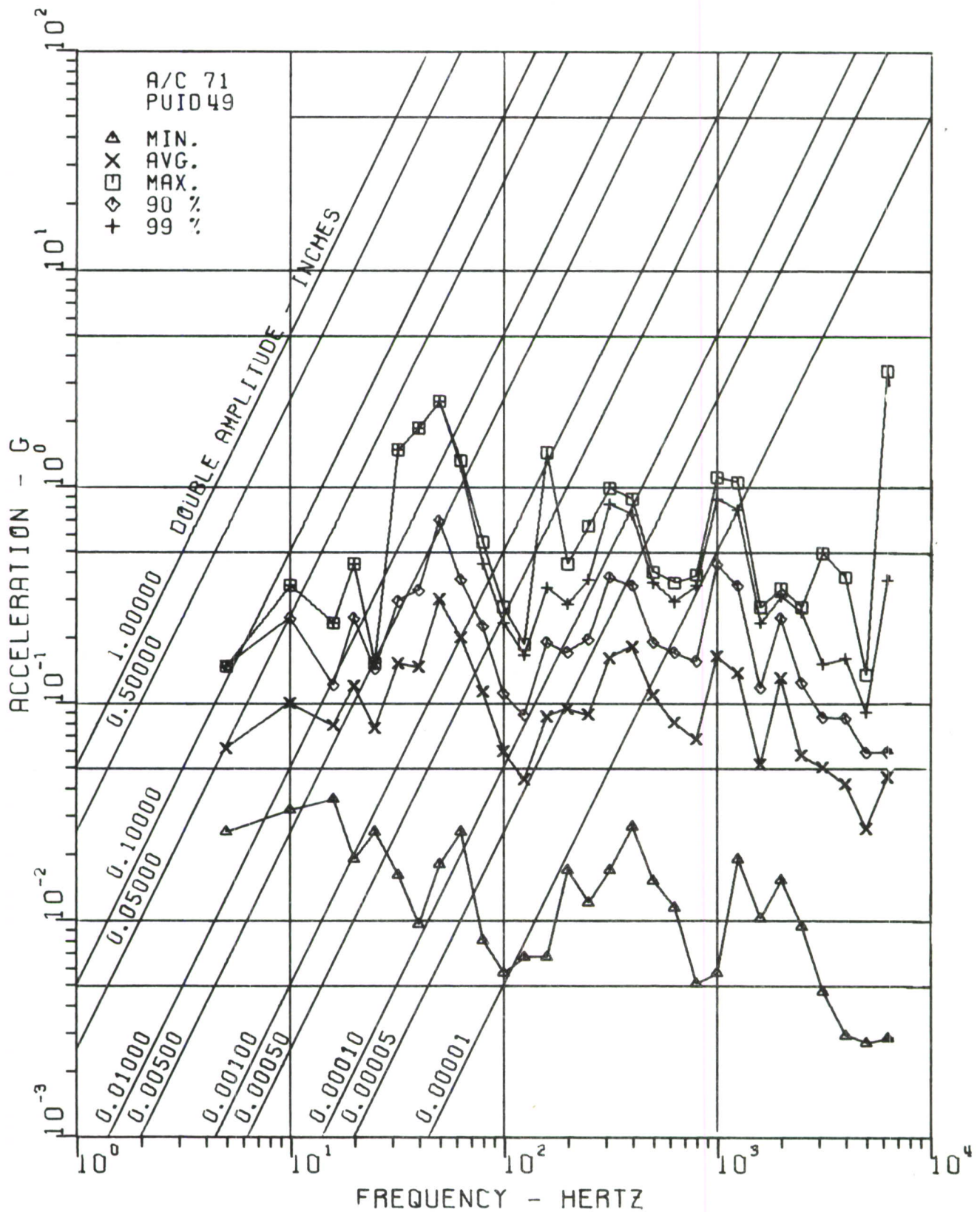


Figure 72. Right Wing, Top Outboard, Sta. 191, without Gunfire

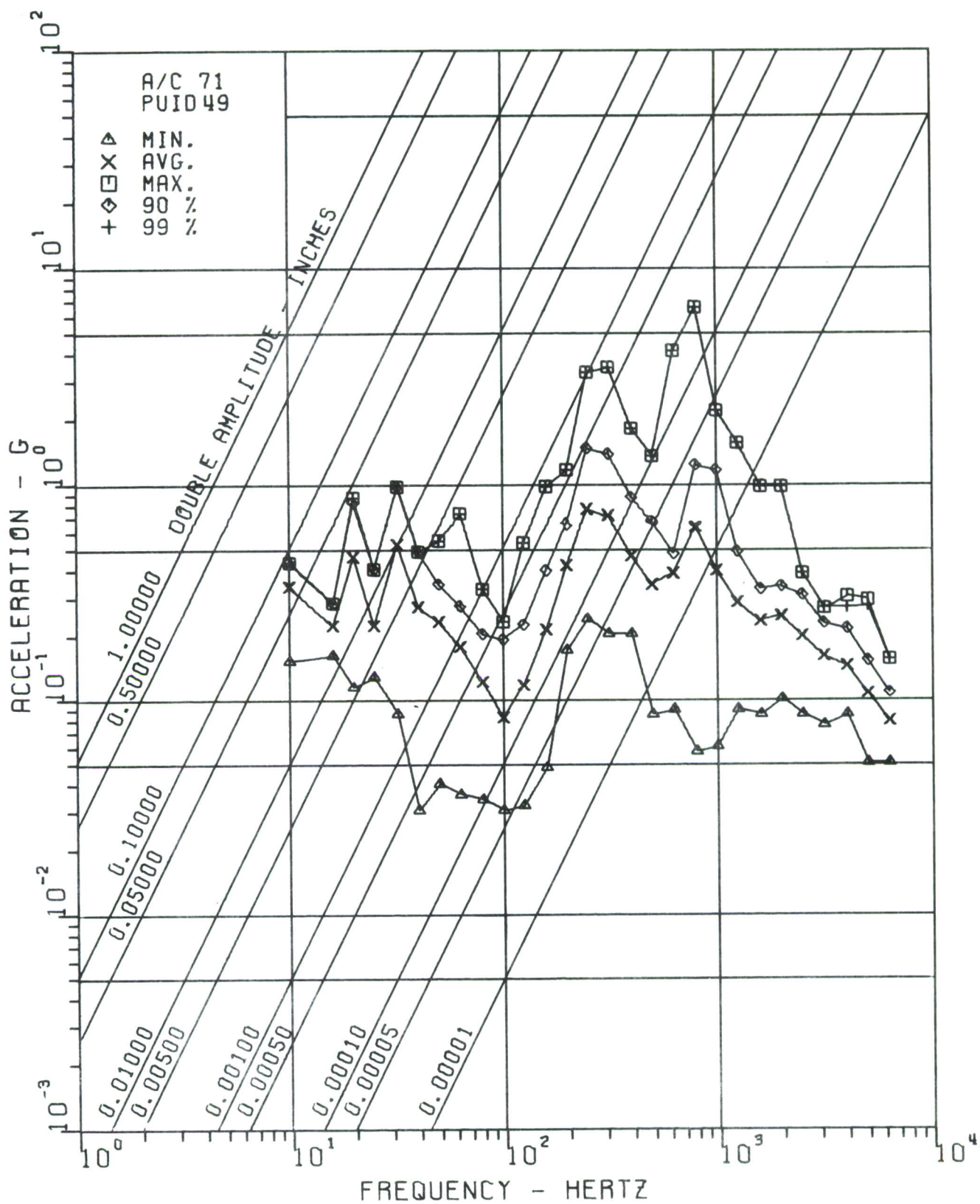


Figure 73. Right Wing, Top Outboard, Sta. 191, with Gunfire

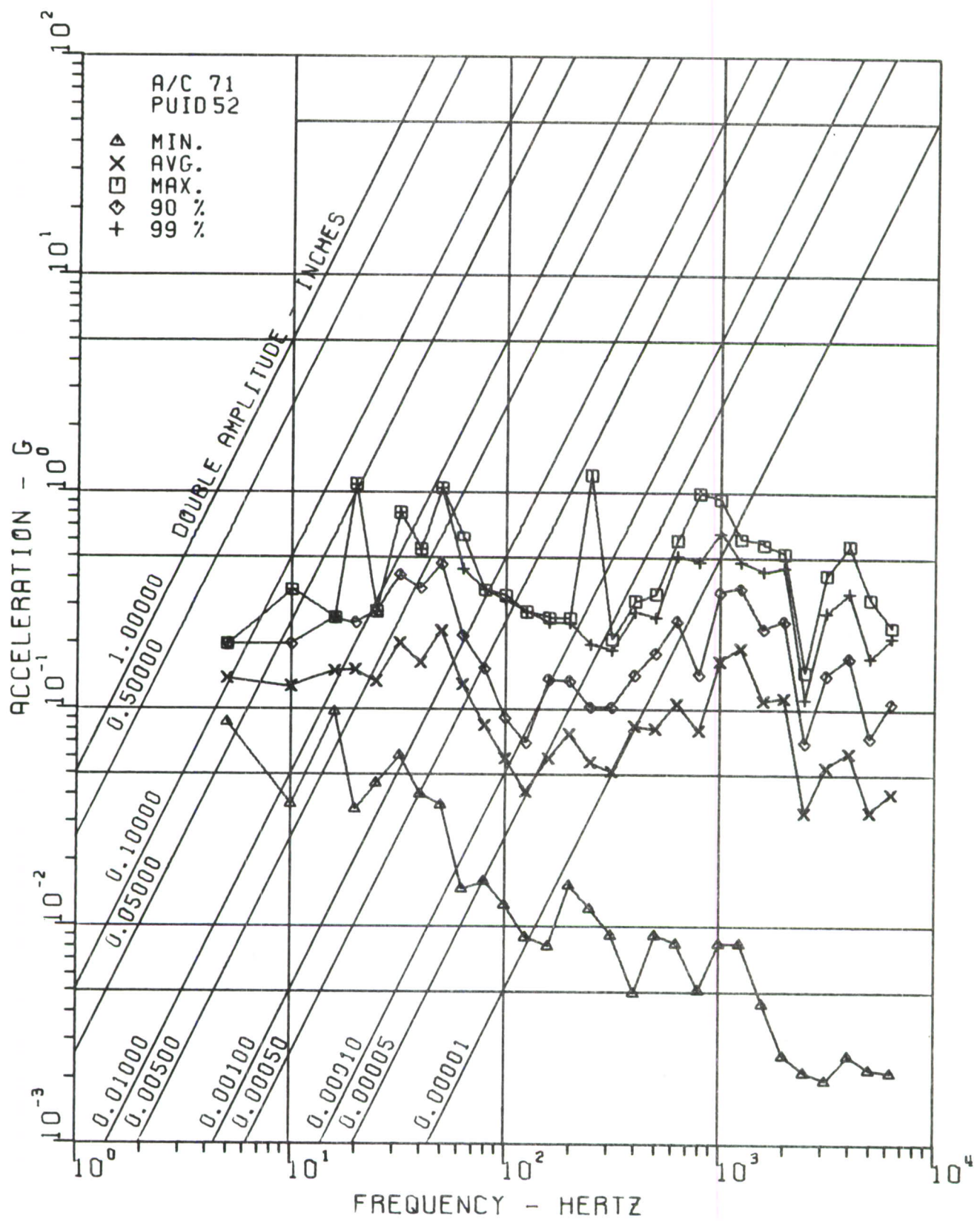


Figure 74. Right Wing, Top Inboard, Sta. 186, without Gunfire

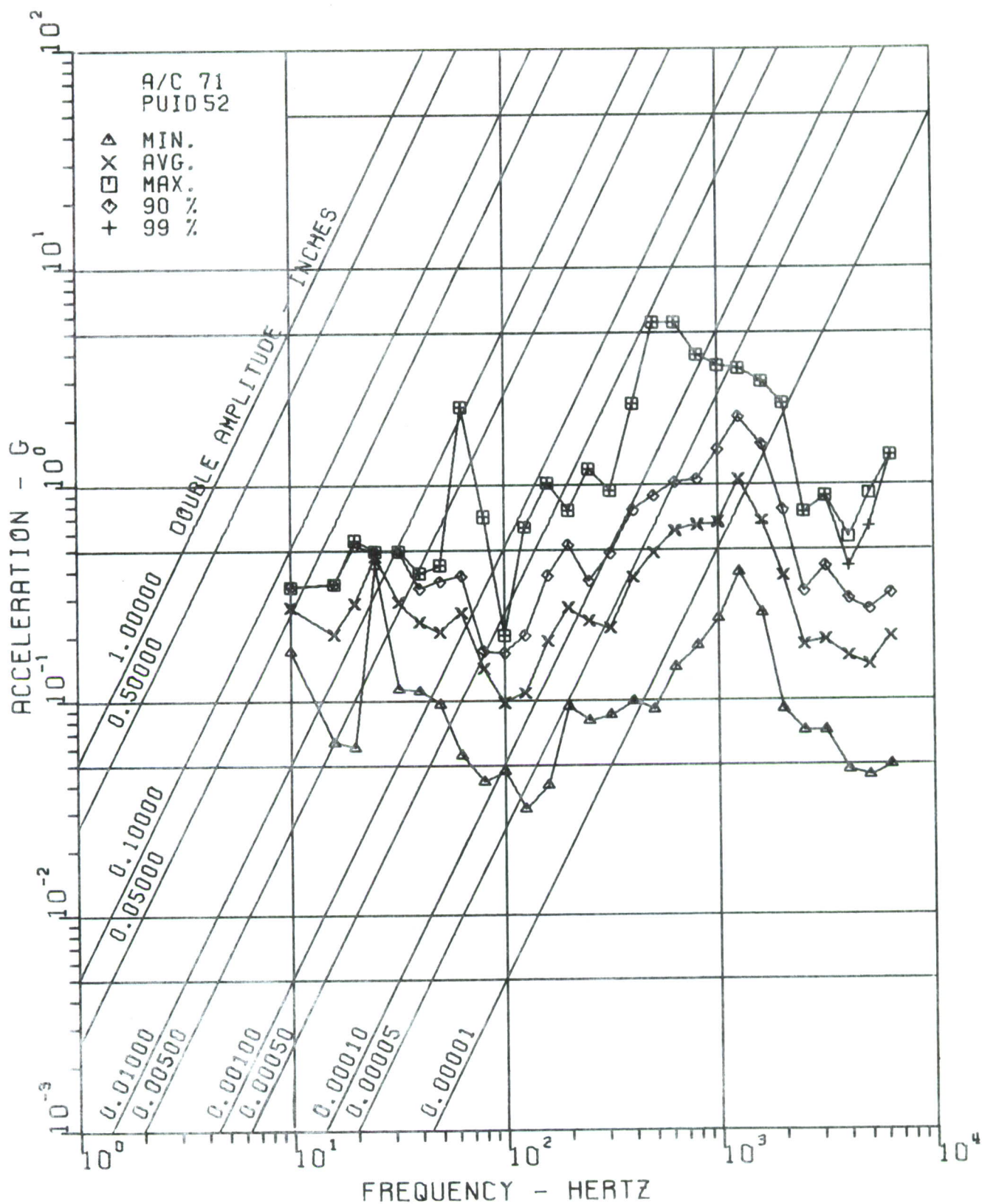


Figure 75. Right Wing, Top Inboard, Sta. 186, with Gunfire

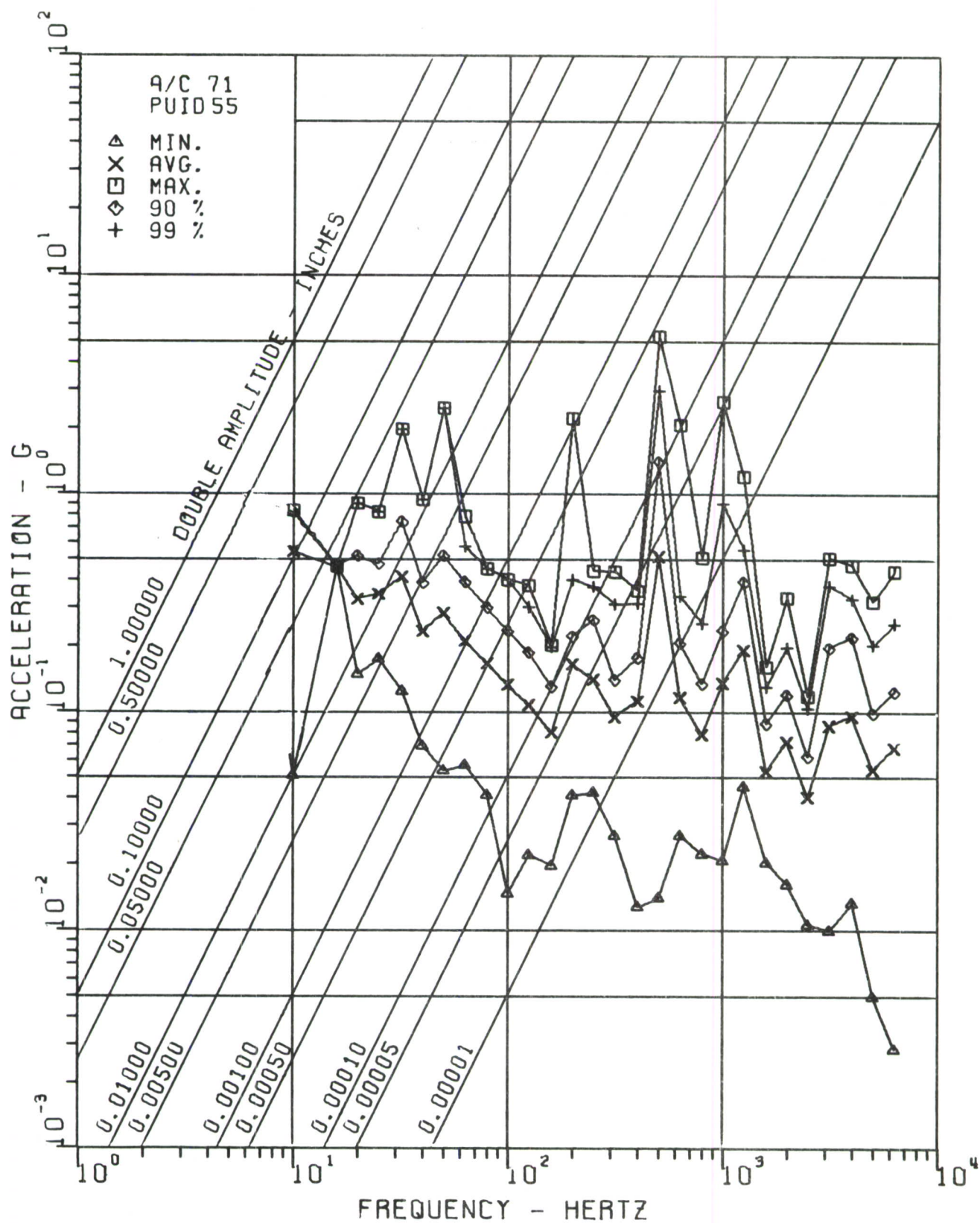


Figure 76. UHF-VHF Antenna Comp., Sta. 179, without Gunfire

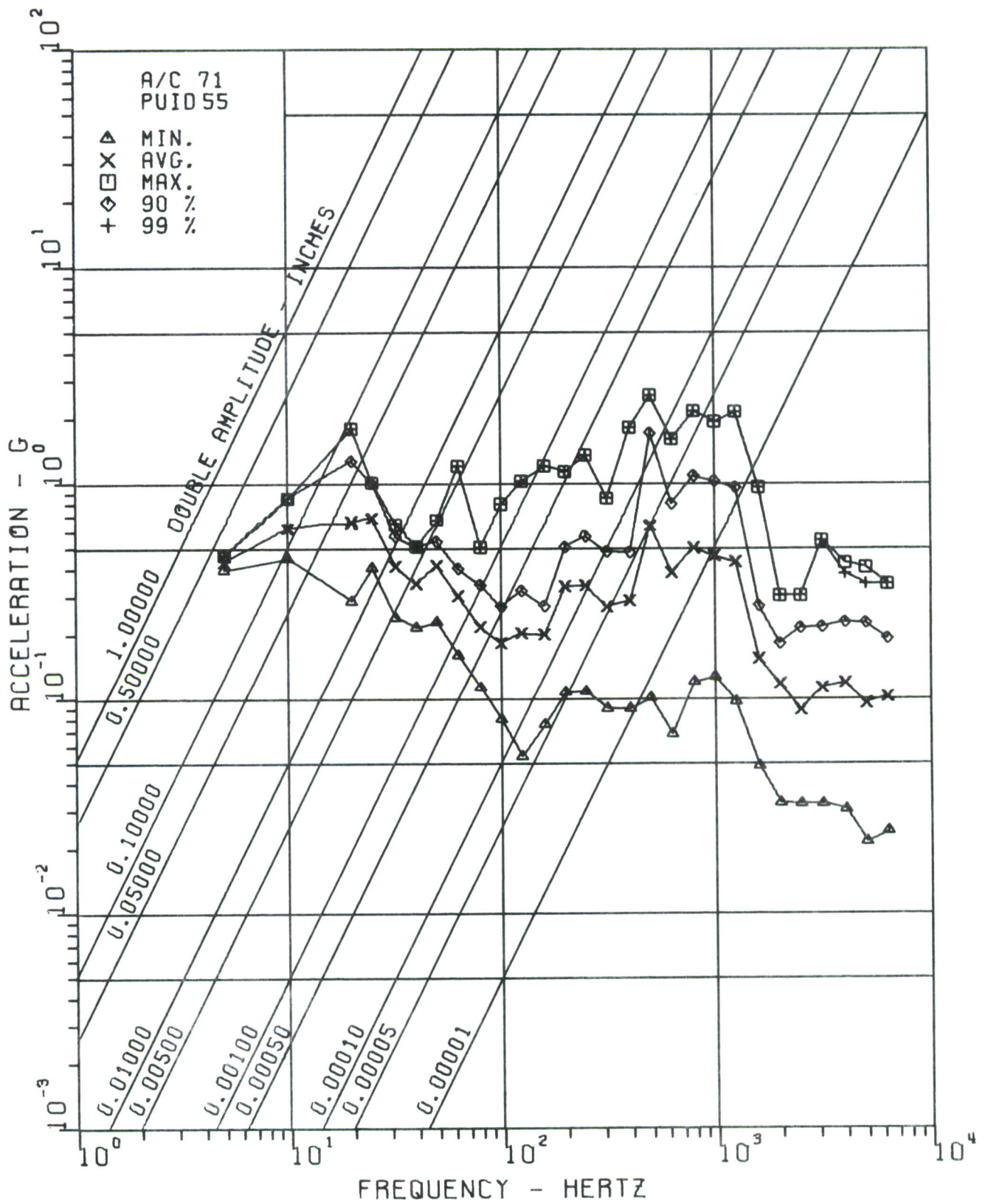


Figure 77. UHF-VHF Antenna Comp., Sta. 179, with Gunfire

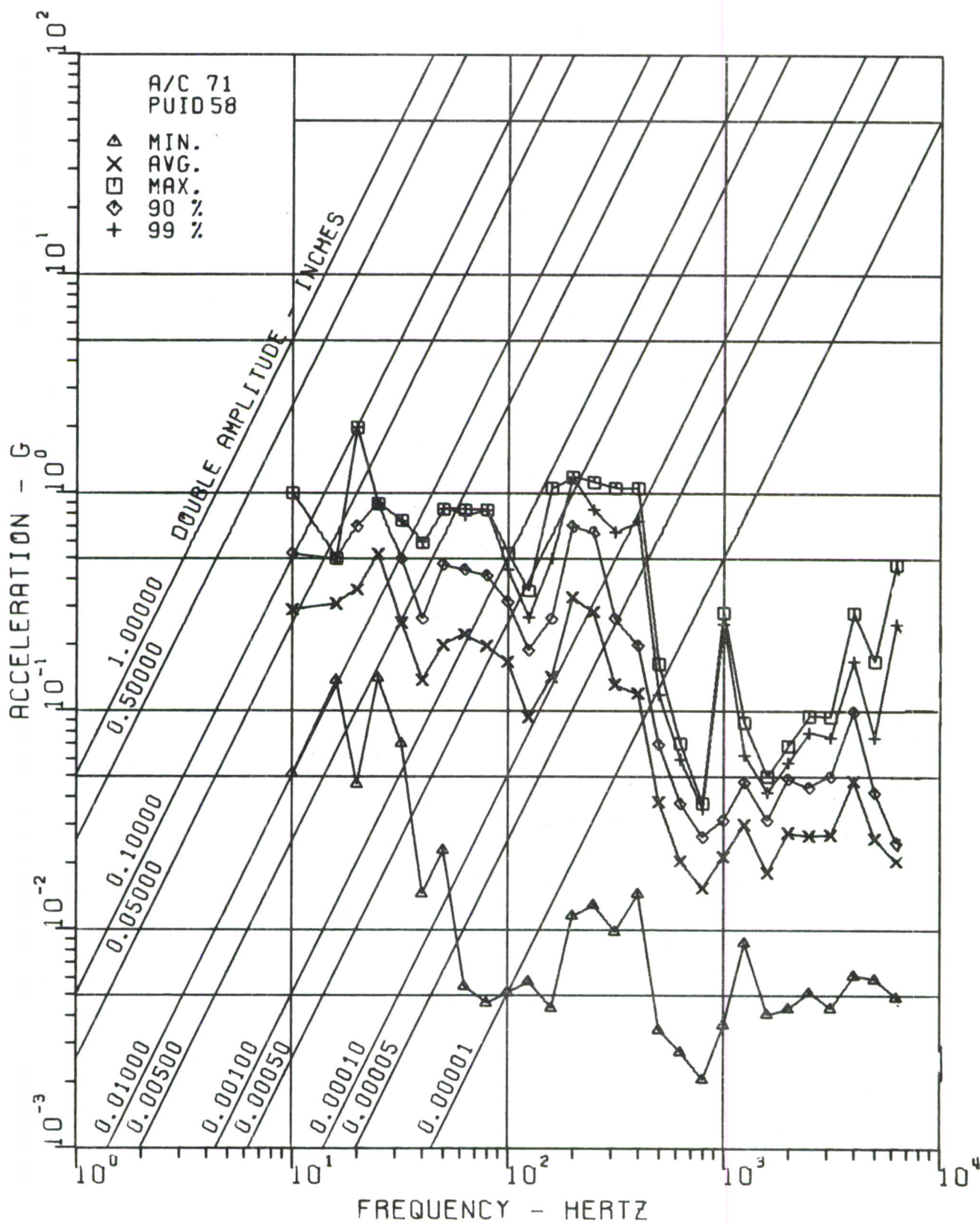


Figure 78. FM Antenna Comp., Sta. 238, without Gunfire

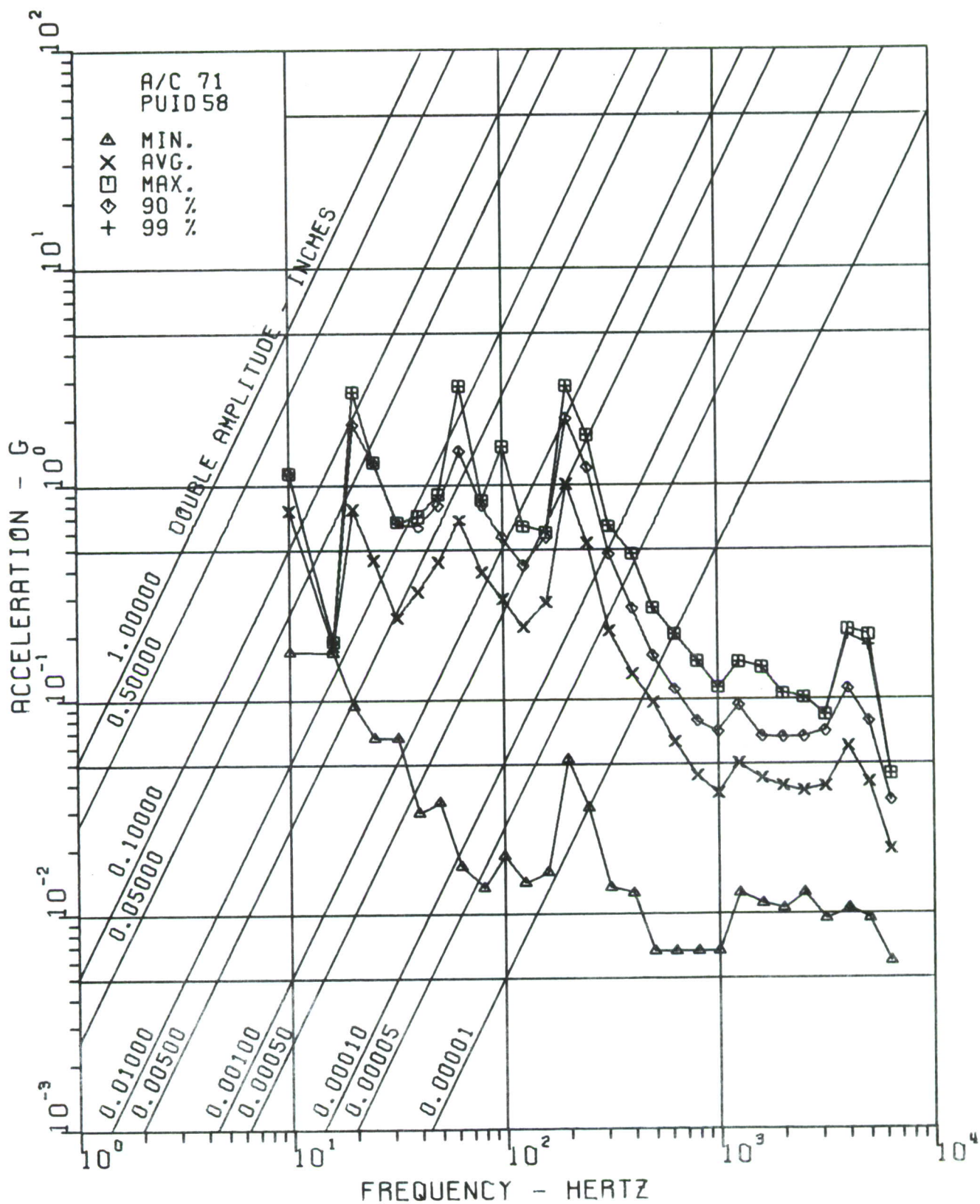


Figure 79. FM Antenna Comp., Sta. 238, with Gunfire

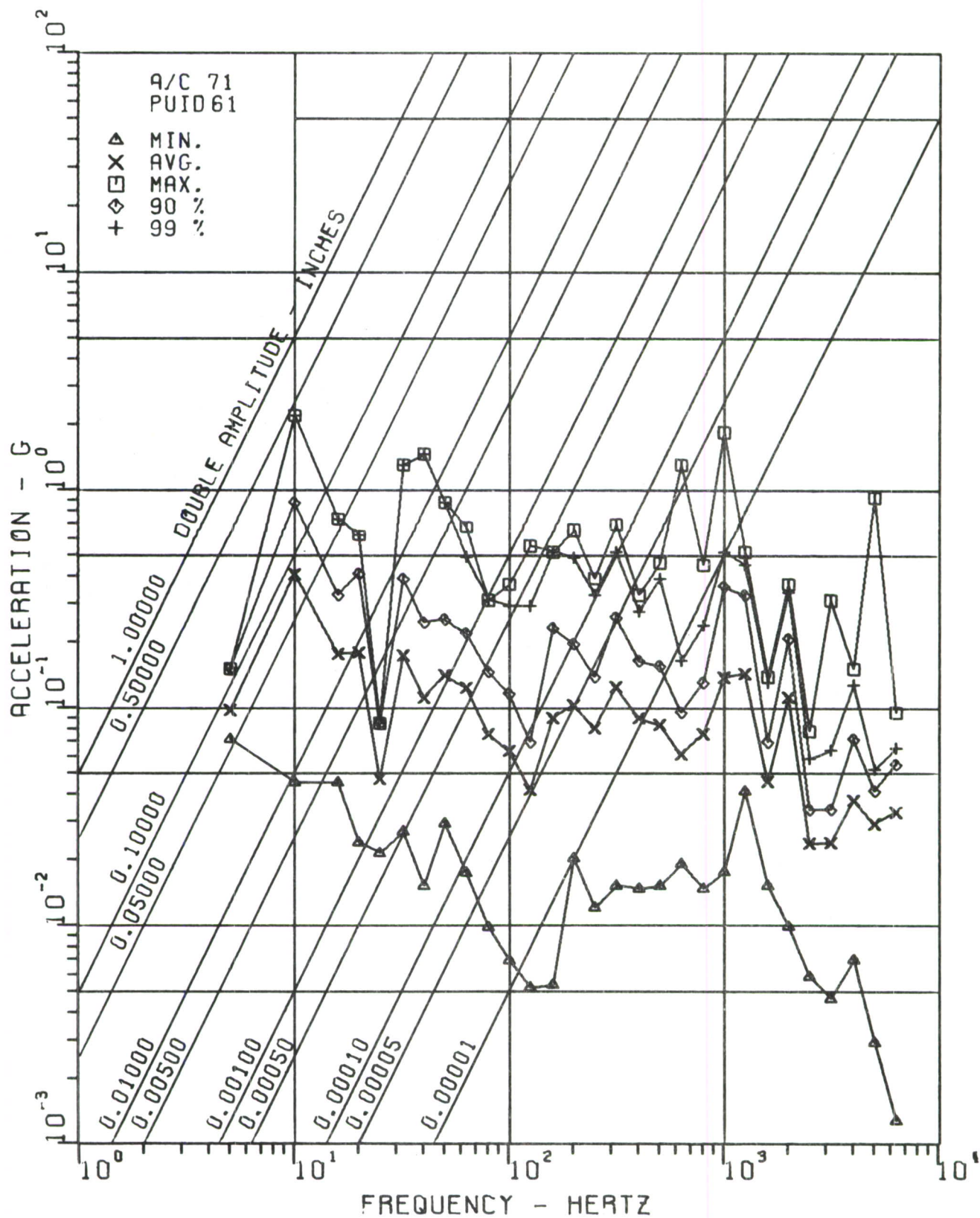


Figure 80. Aft Electrical Comp. near AN/ARN-83 Direction Finder,
Sta. 279, without Gunfire

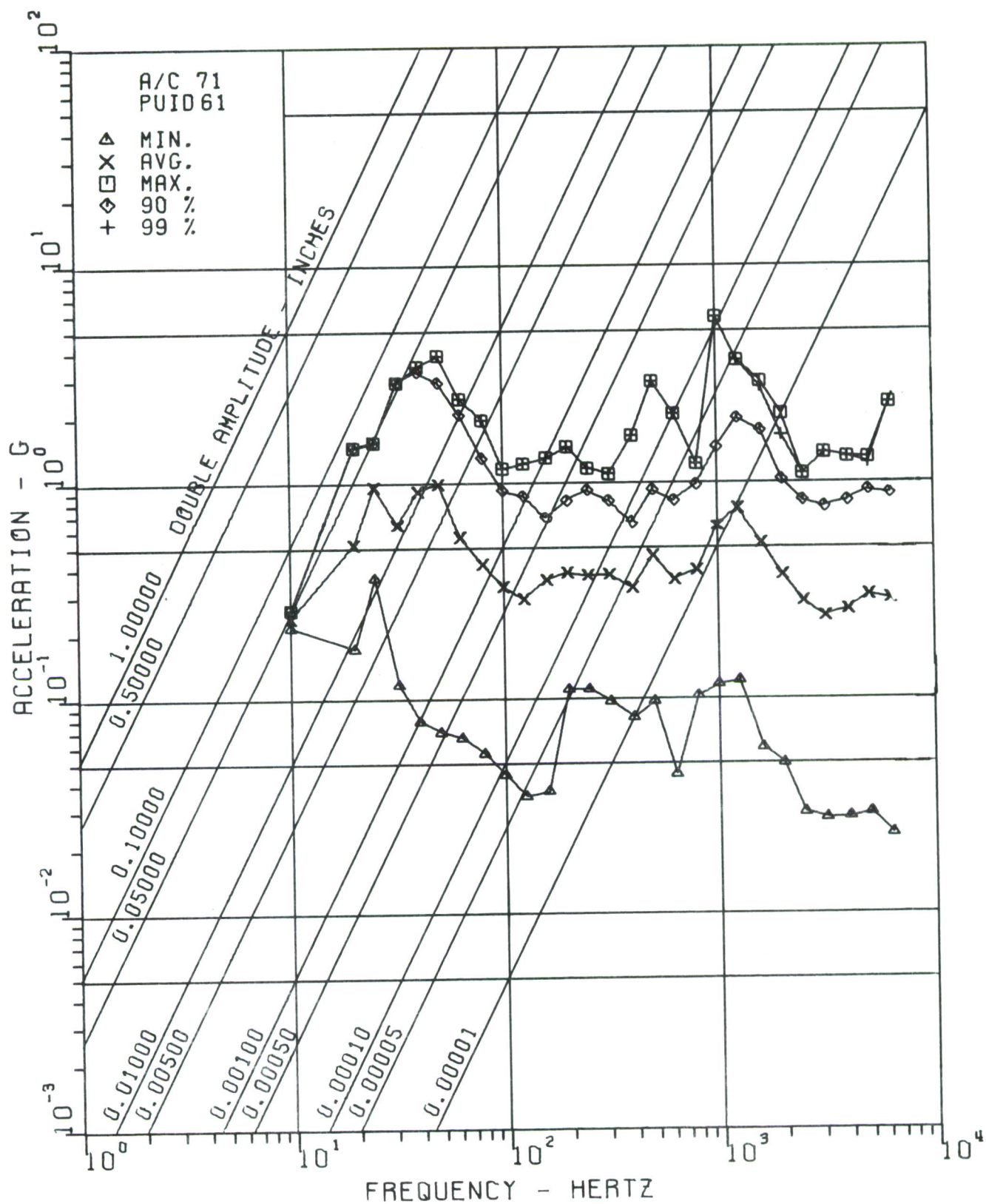


Figure 81. Aft Electrical Comp. near AN/ARN-83 Direction Finder, Sta. 279, with Gunfire

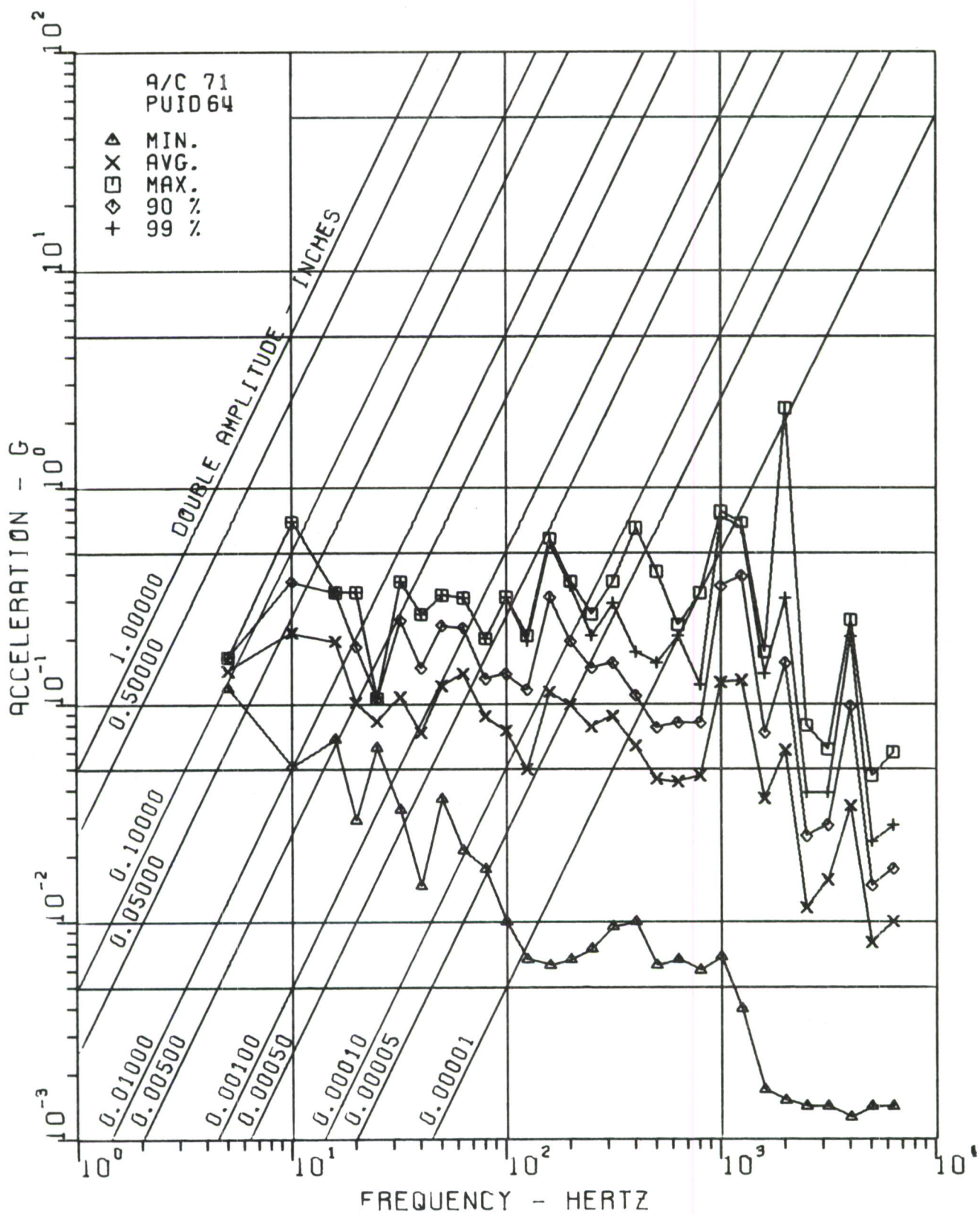


Figure 82. Aft Electrical Comp. near AN/ASN-43 Gyro Compass,
Sta. 291, without Gunfire

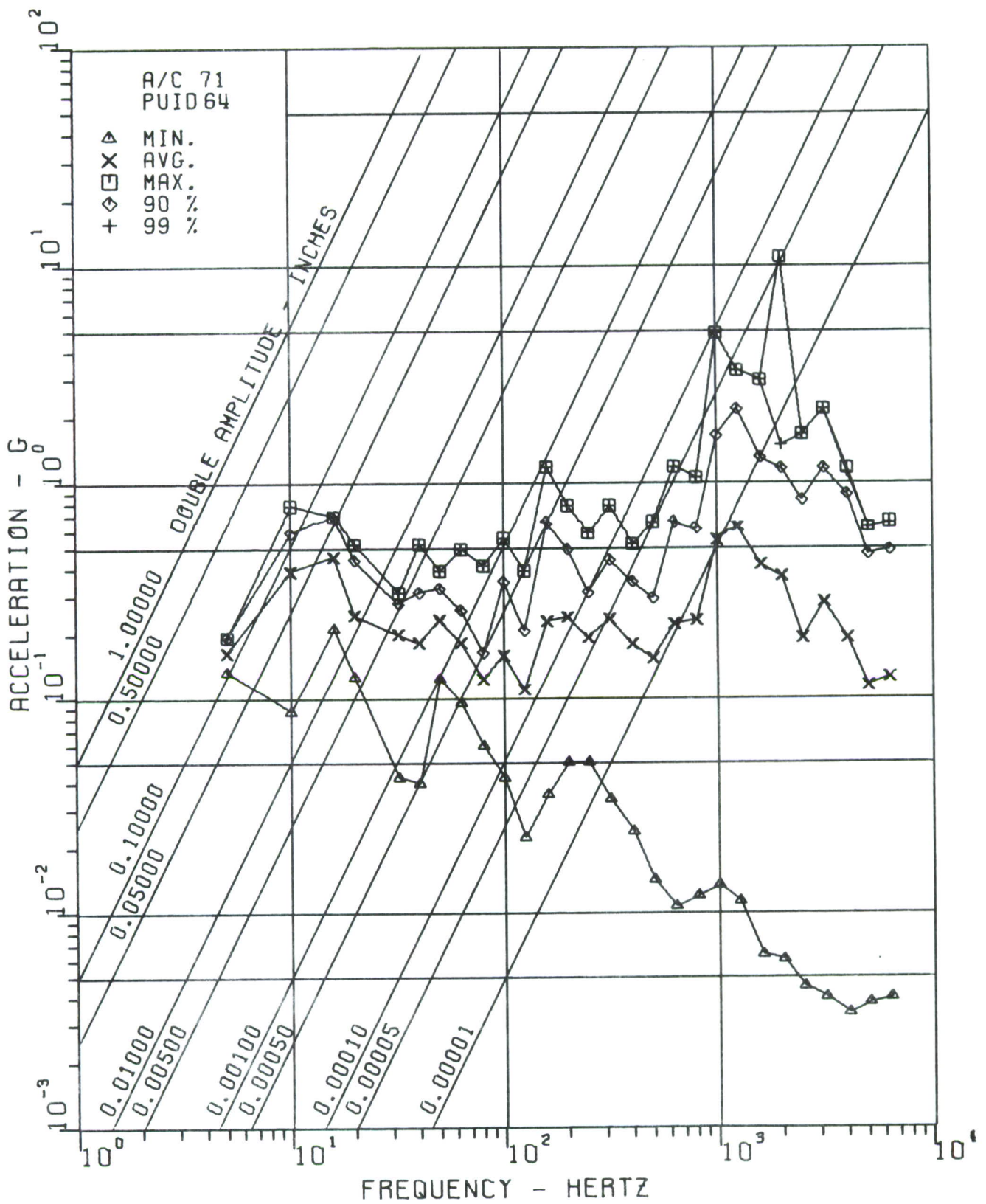


Figure 83. Aft Electrical Comp. near AN/ASN-43 Gyro Compass, Sta. 291, with Gunfire

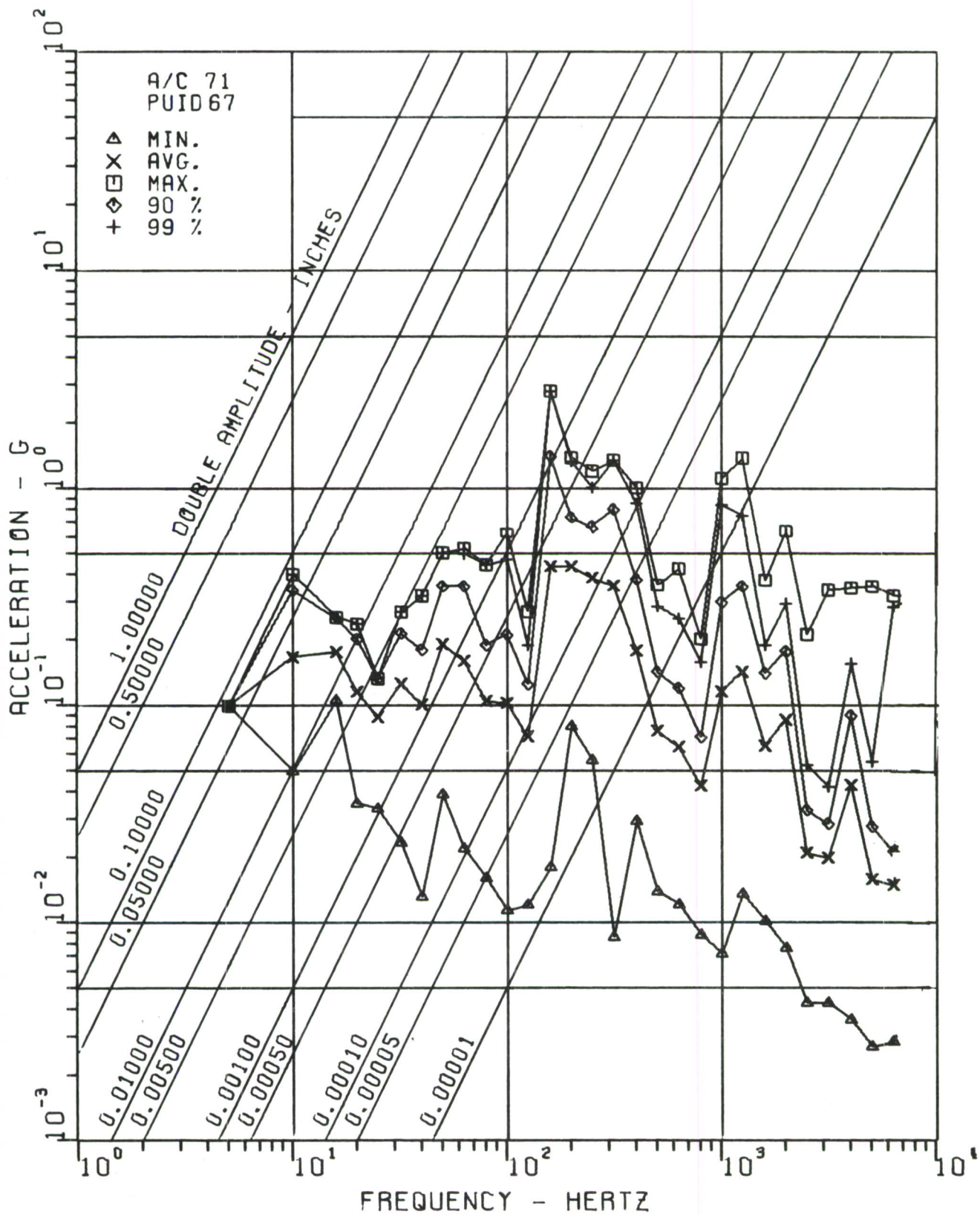


Figure 84. Structure near AN/APX-72 Transponder, Sta. 330, without Gunfire

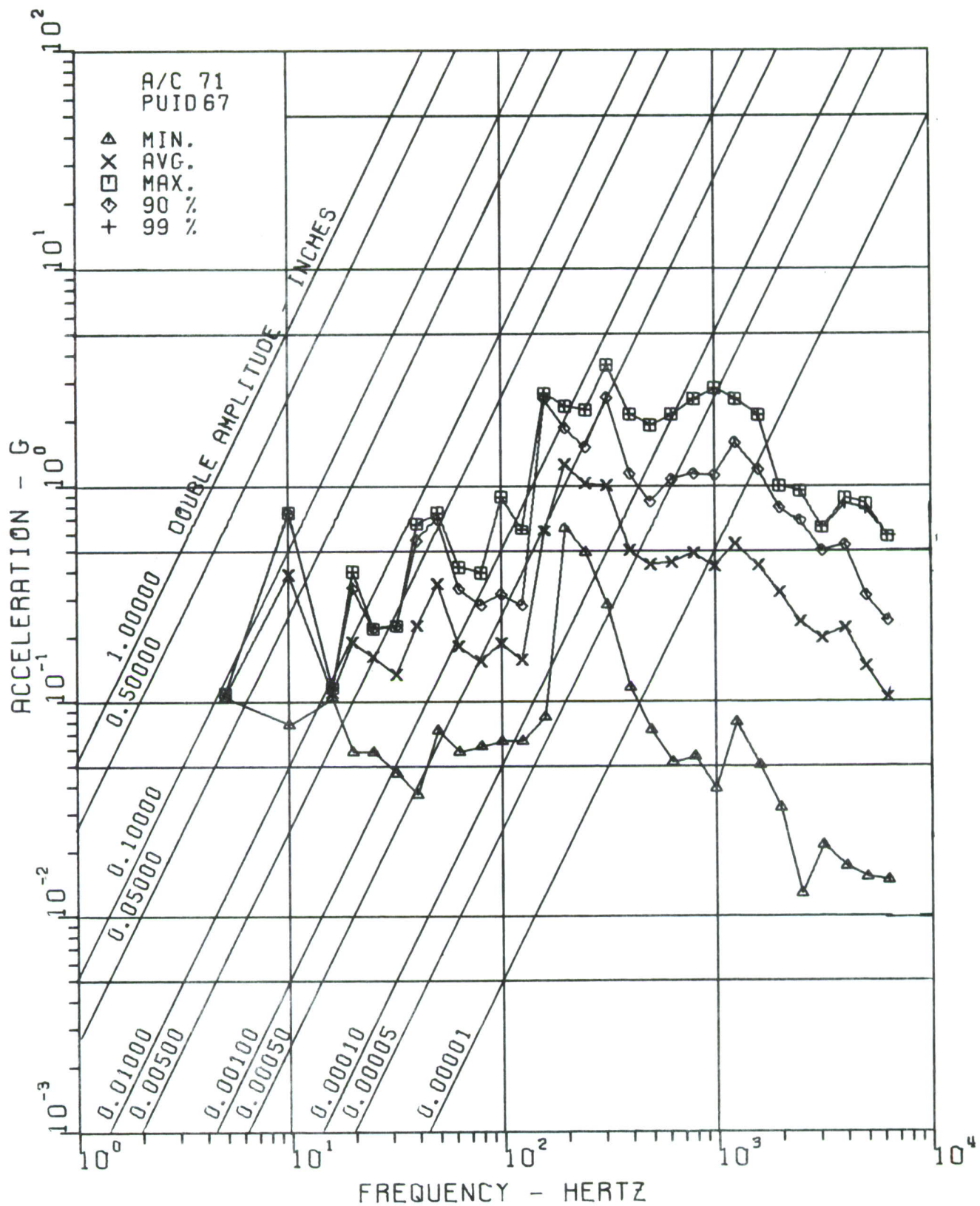


Figure 85. Structure near AN/APX-72 Transponder, Sta. 330, with Gunfire

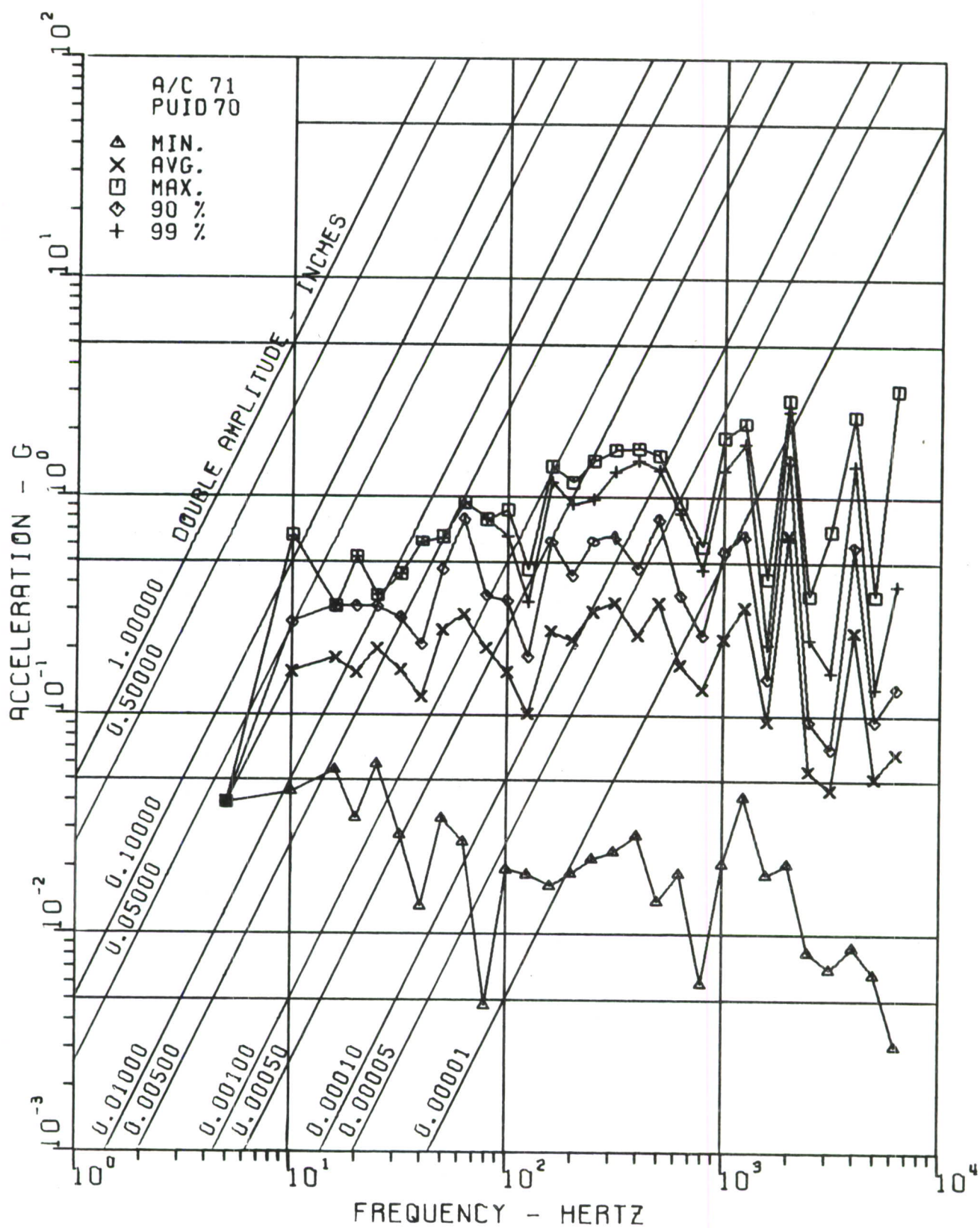


Figure 86. Tail Boom, Sta. 400, without Gunfire

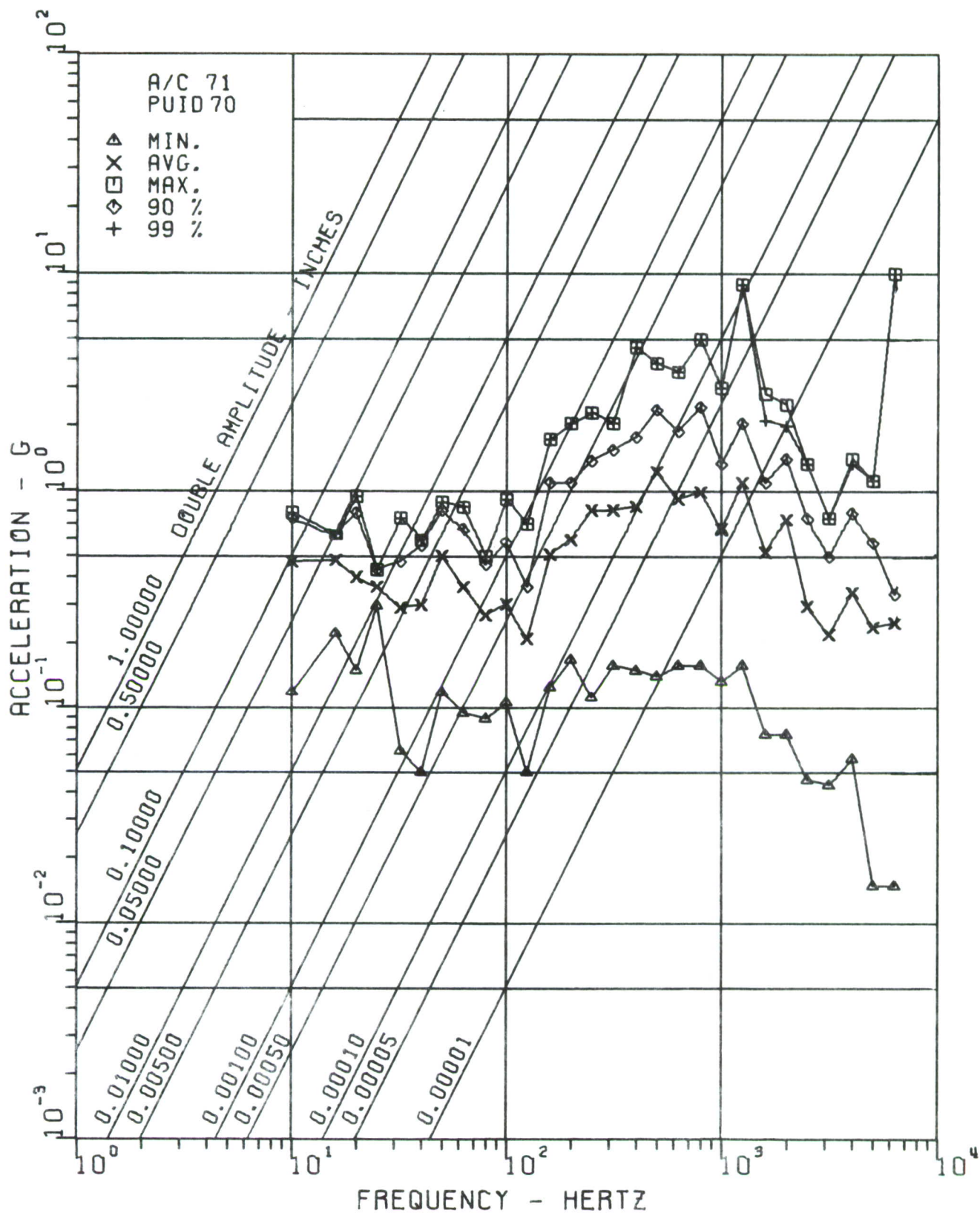


Figure 87. Tail Boom, Sta. 400, with Gunfire

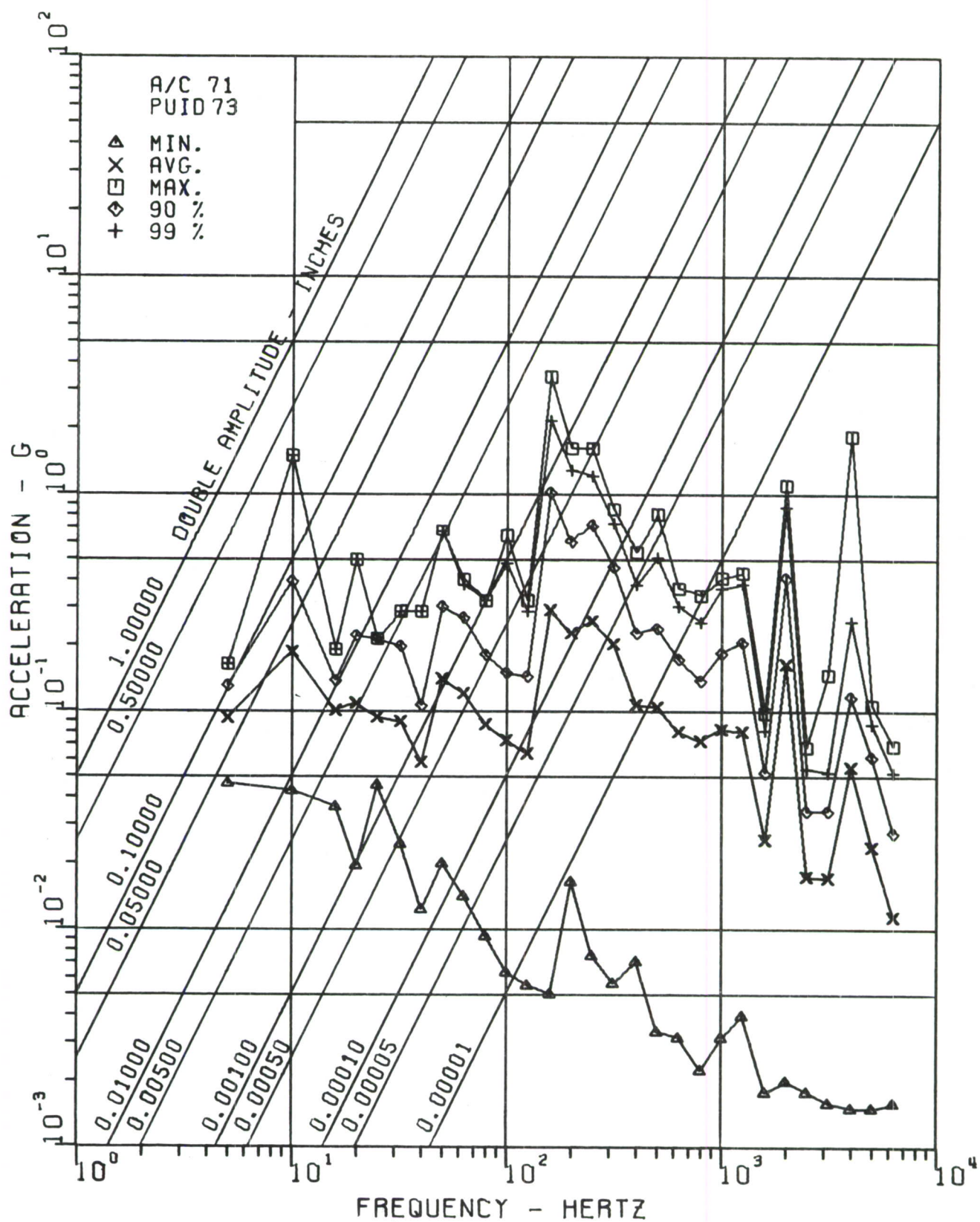


Figure 88. Radio Compartment near AN/ARC-51 Transceiver, Sta. 346, without Gunfire

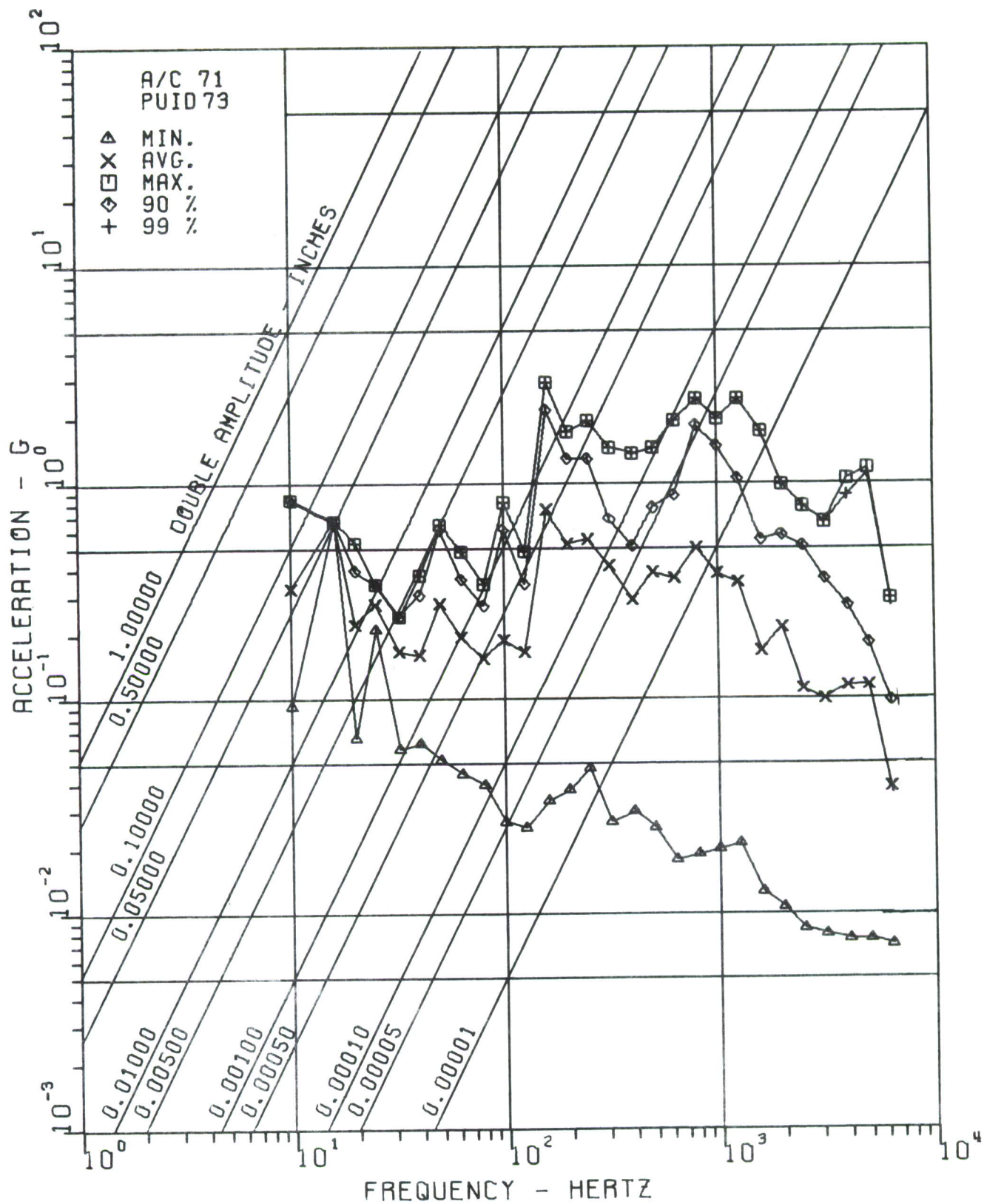


Figure 89. Radio Compartment near AN/ARC-51 Transceiver, Sta. 346, with Gunfire

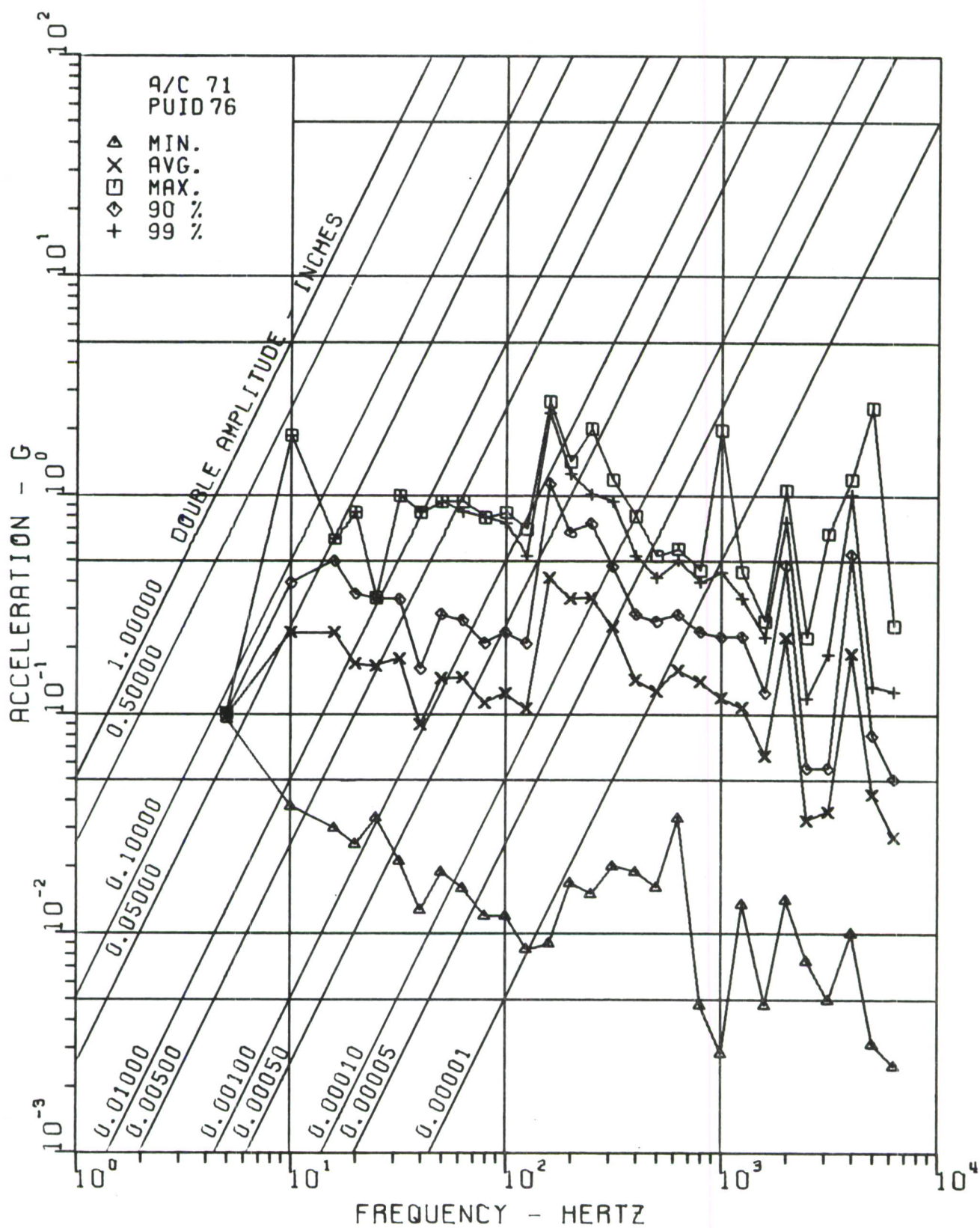


Figure 90. Radio Compartment near AN/ARC-134 Transceiver, Sta. 364, without Gunfire

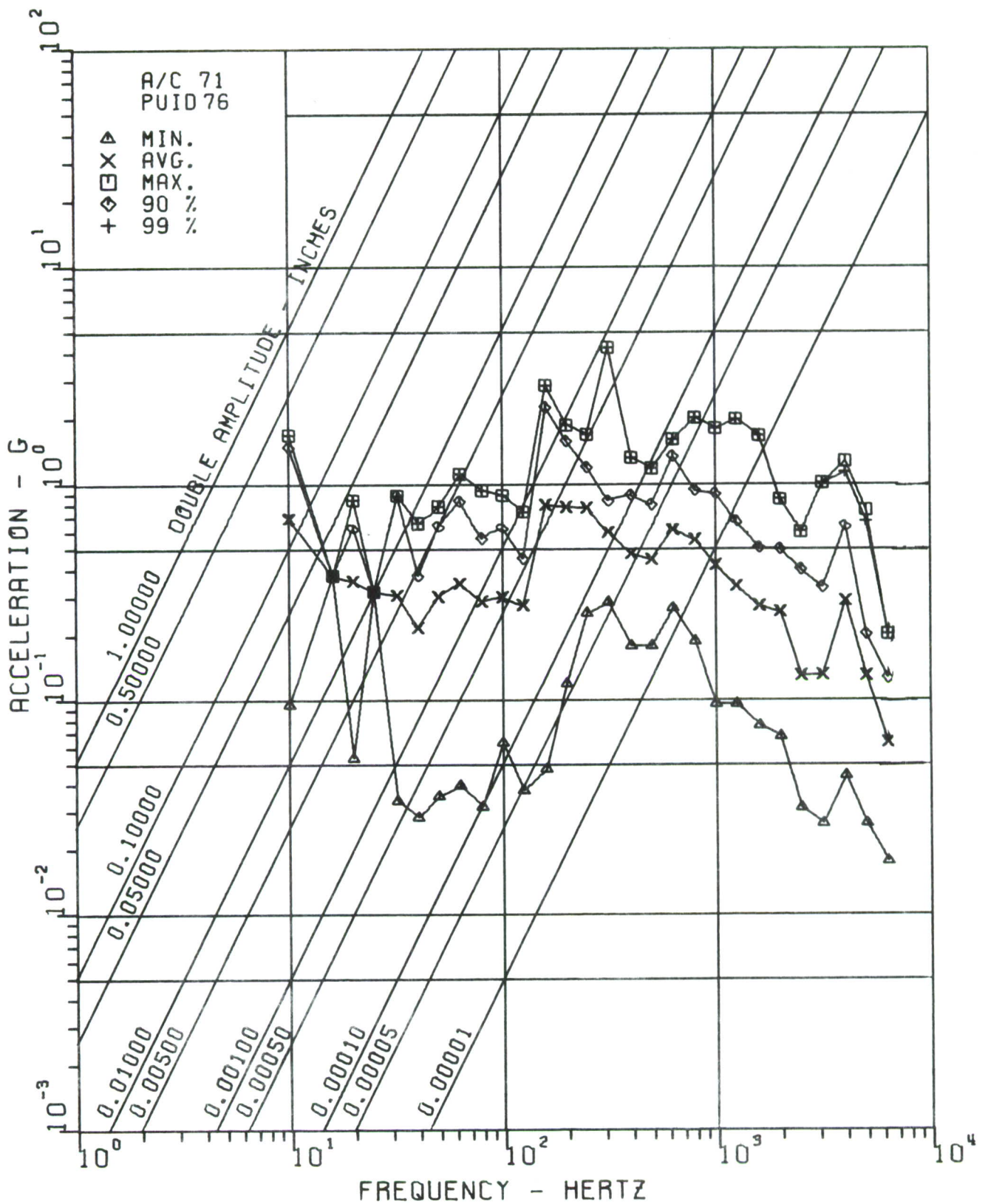


Figure 91. Radio Compartment near AN/ARC-134 Transceiver, Sta. 364, with Gunfire

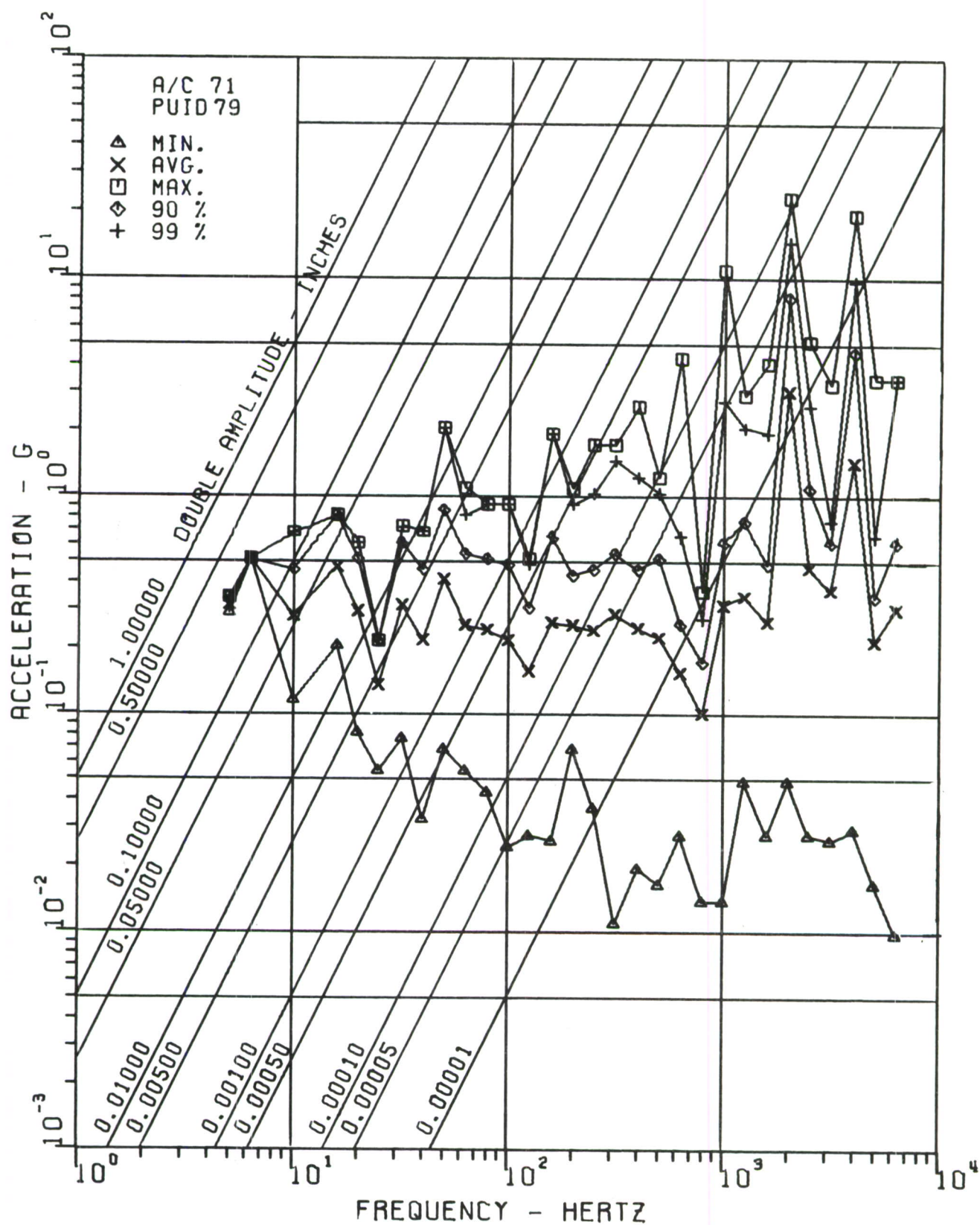


Figure 92. Tail Boom near 45° Gear Box, Sta. 470, without Gunfire

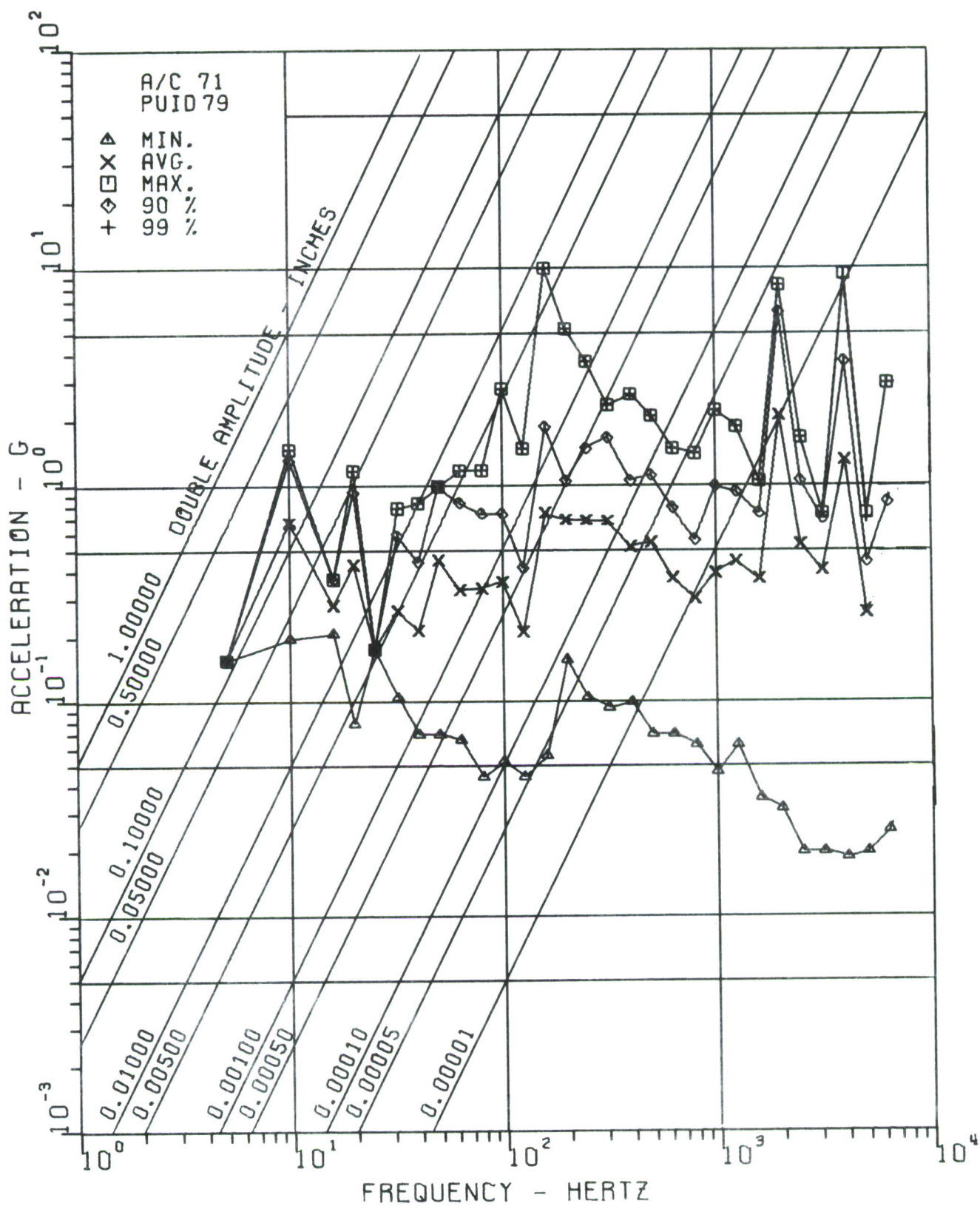


Figure 93. Tail Boom near 45° Gear Box, Sta. 470, with Gunfire

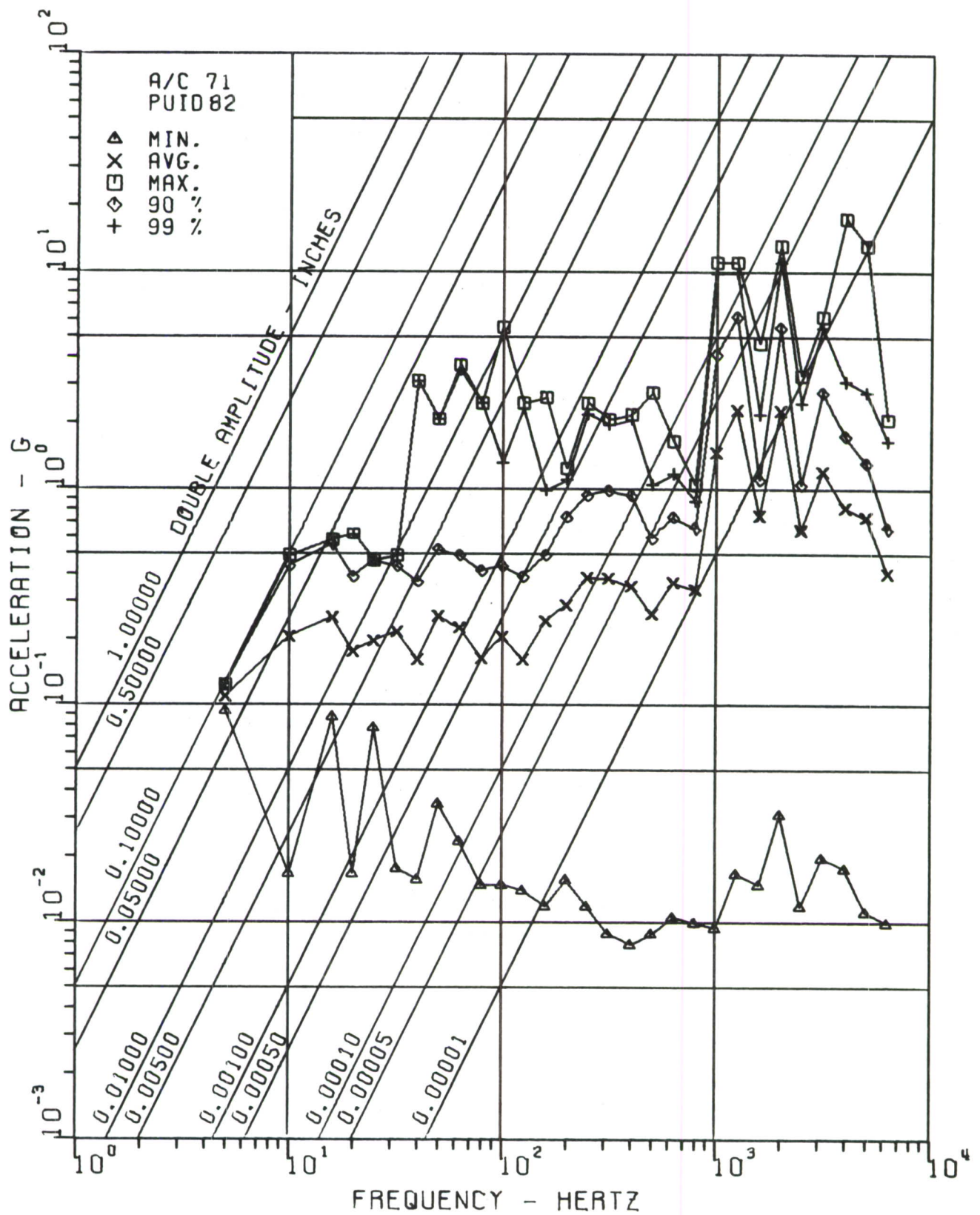


Figure 94. Tail Boom near 90° Gear Box, Sta. 520, without Gunfire

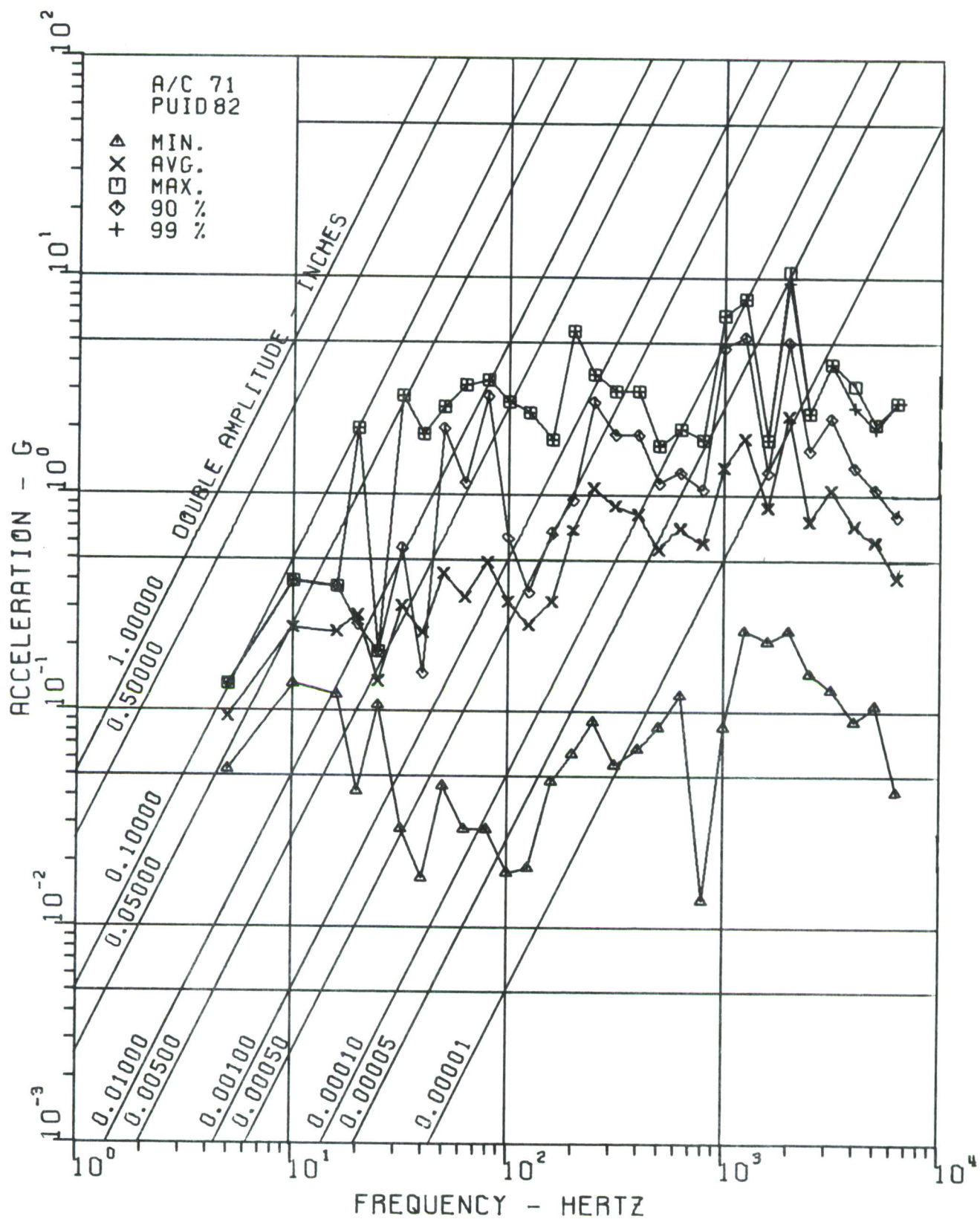


Figure 95. Tail Boom near 90° Gear Box, Sta. 520, with Gunfire

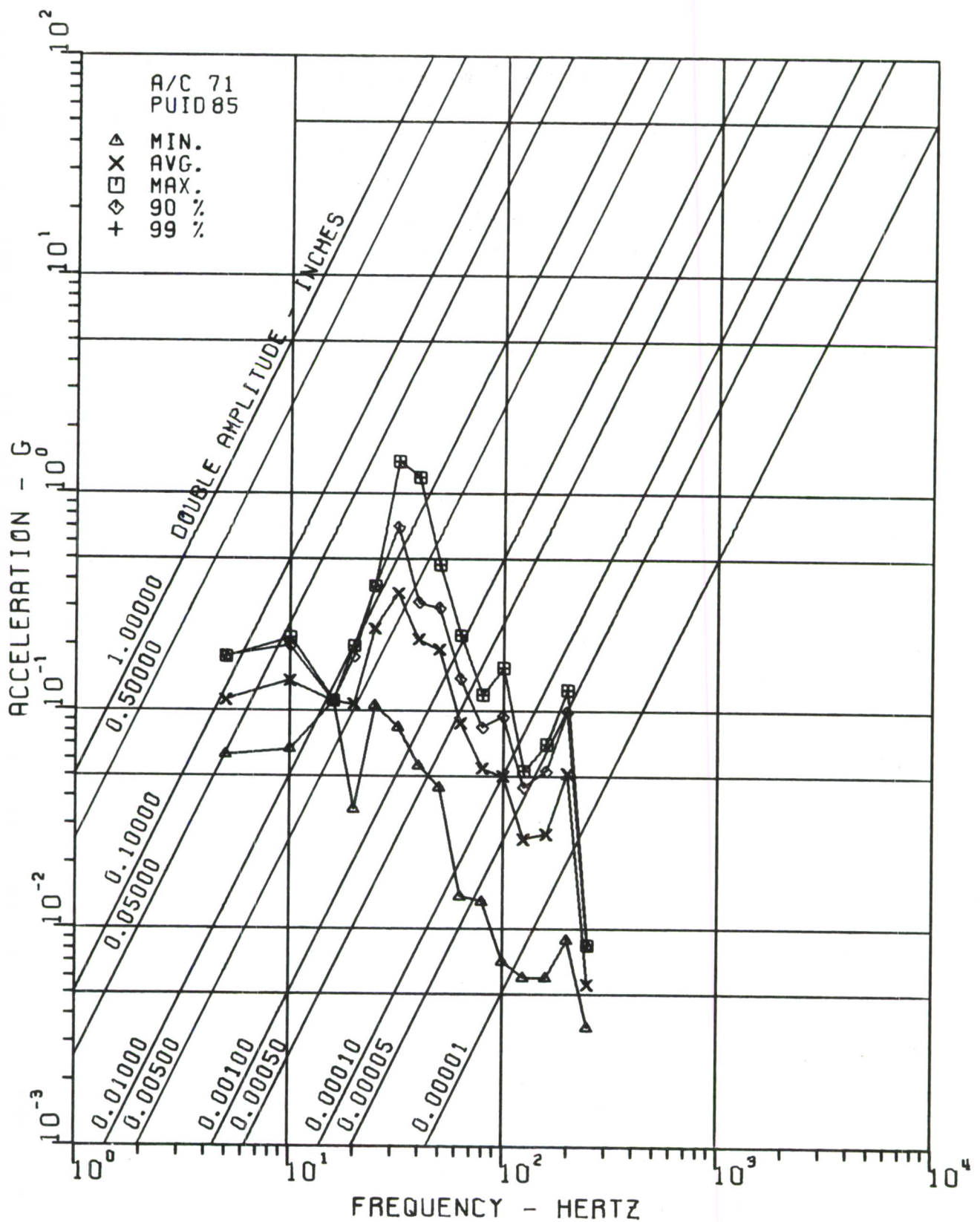


Figure 96. Gunner's Instrument Panel, Left Side, Sta. 60, without Gunfire

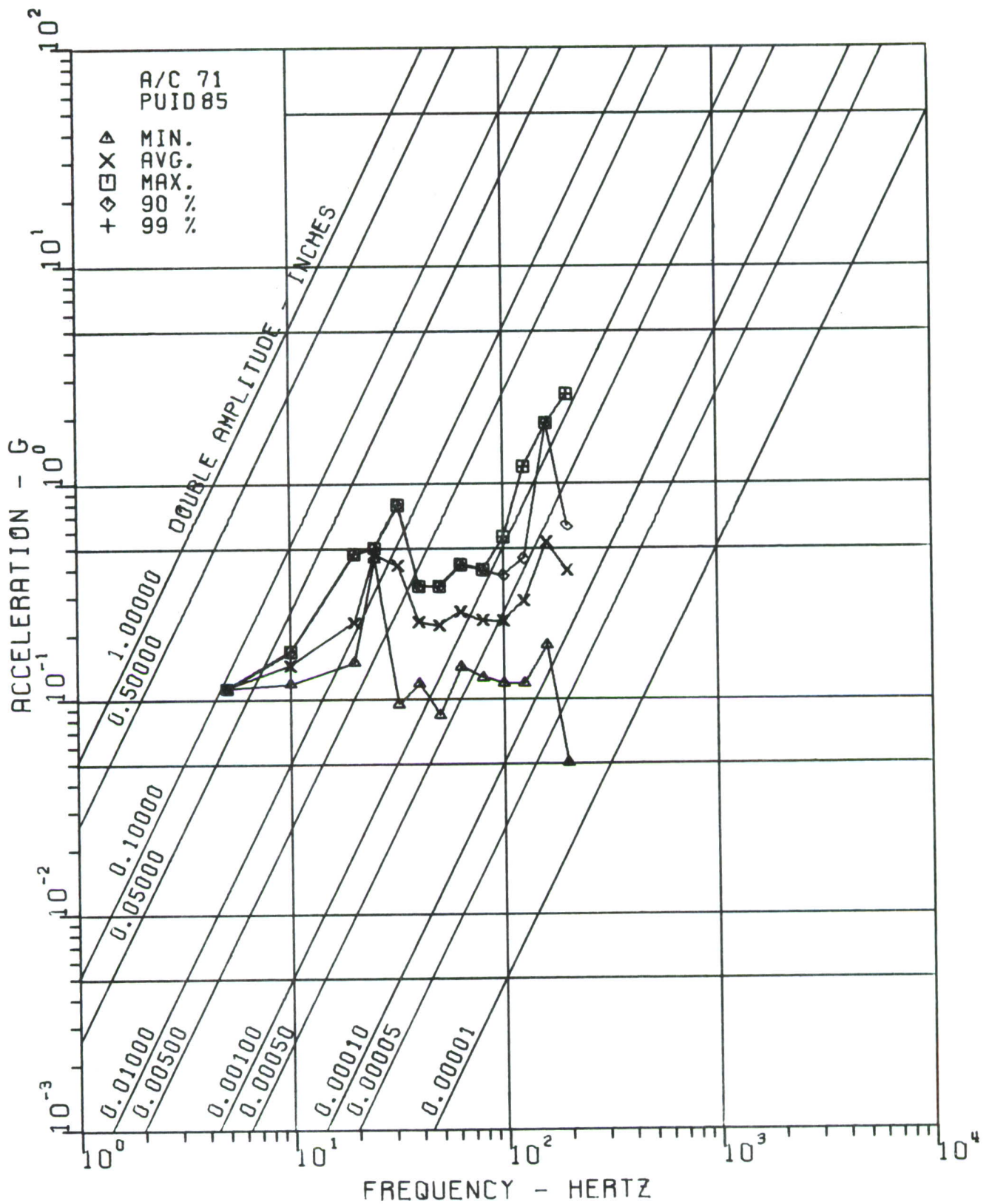


Figure 97. Gunner's Instrument Panel, Left Side, Sta. 60, with Gunfire

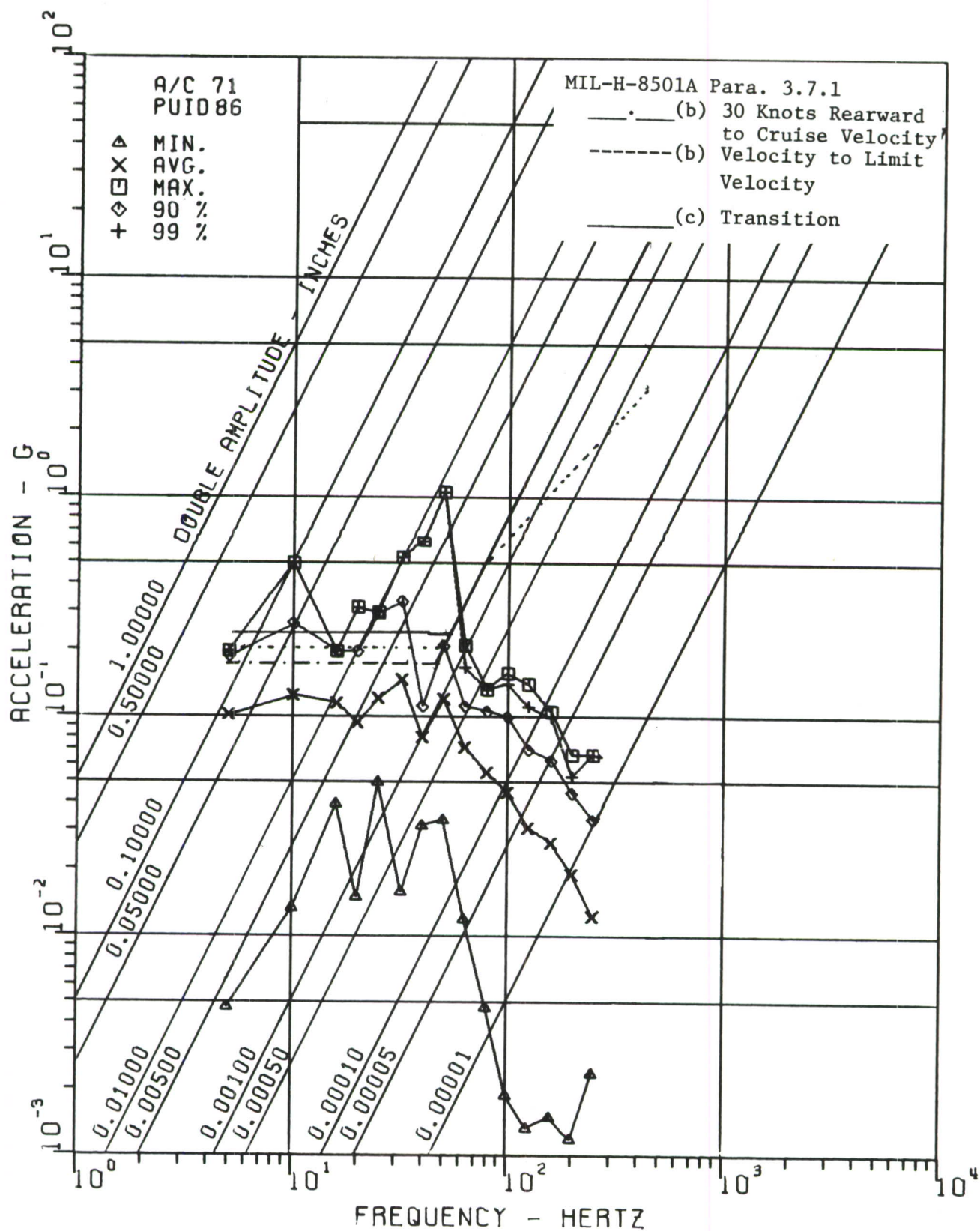


Figure 98. Gunner's Floor, Sta. 68, without Gunfire

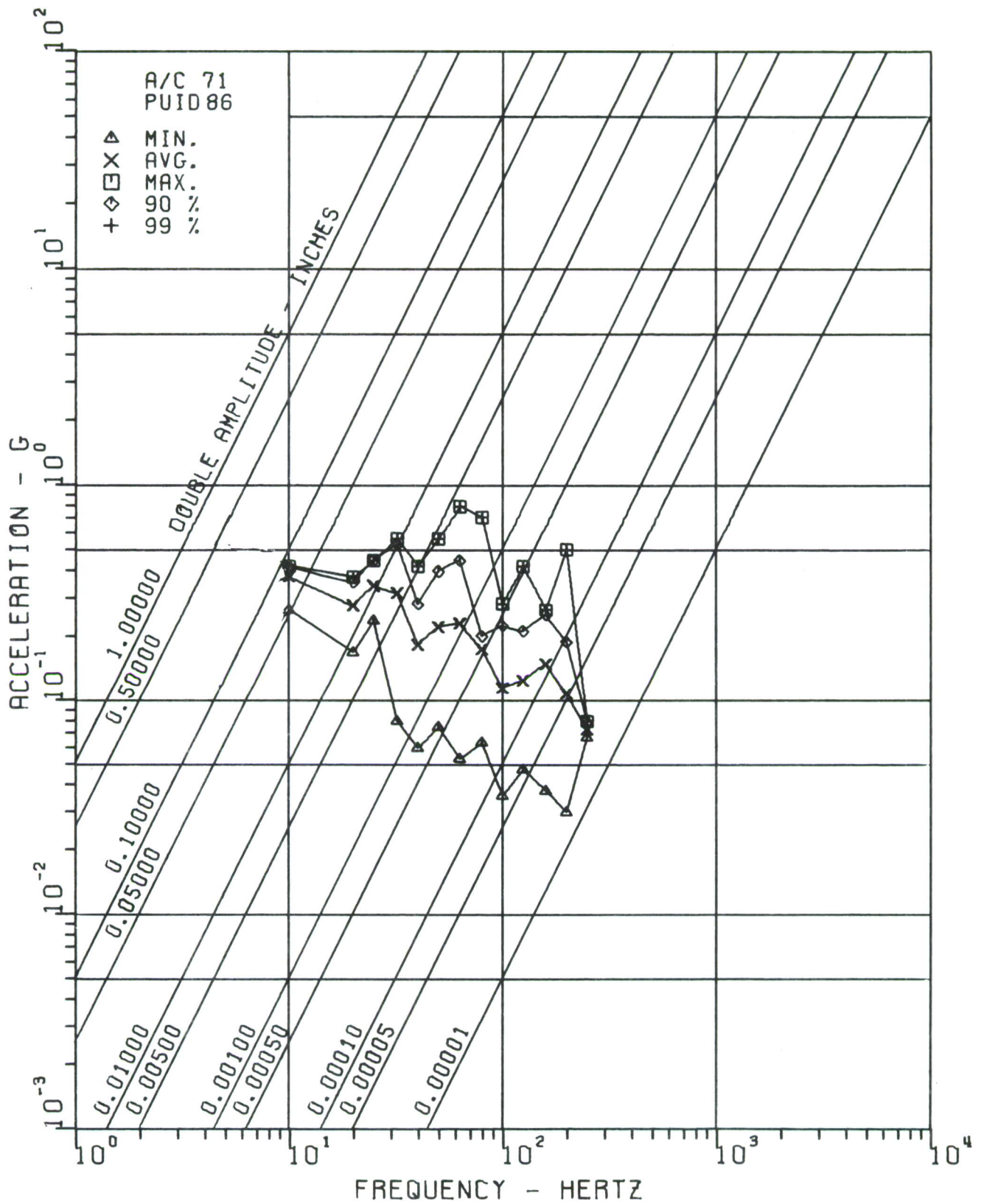


Figure 99. Gunner's Floor, Sta. 68, with Gunfire

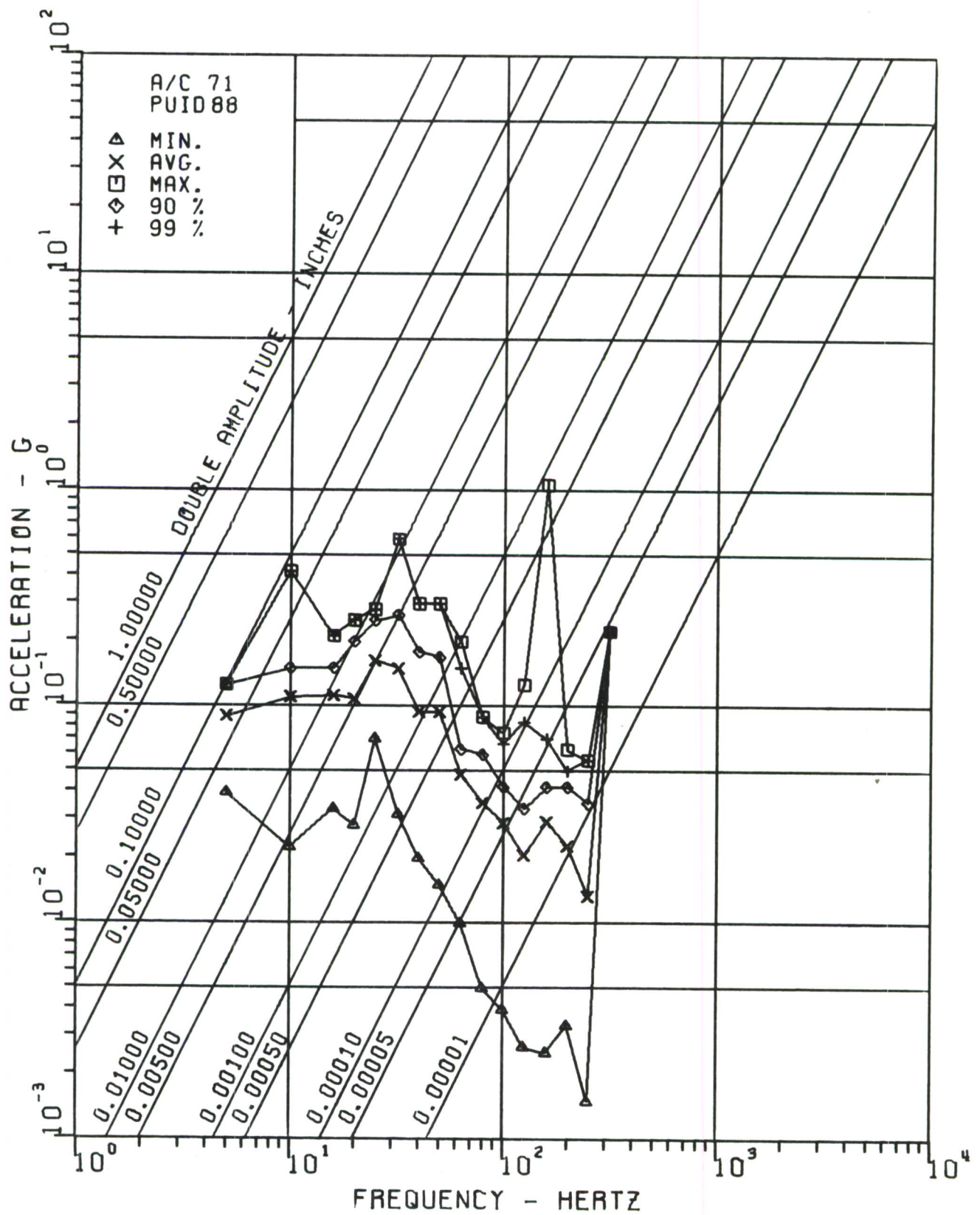


Figure 100. Pilot's Instrument Panel, Right Side, Sta. 115, without Gunfire

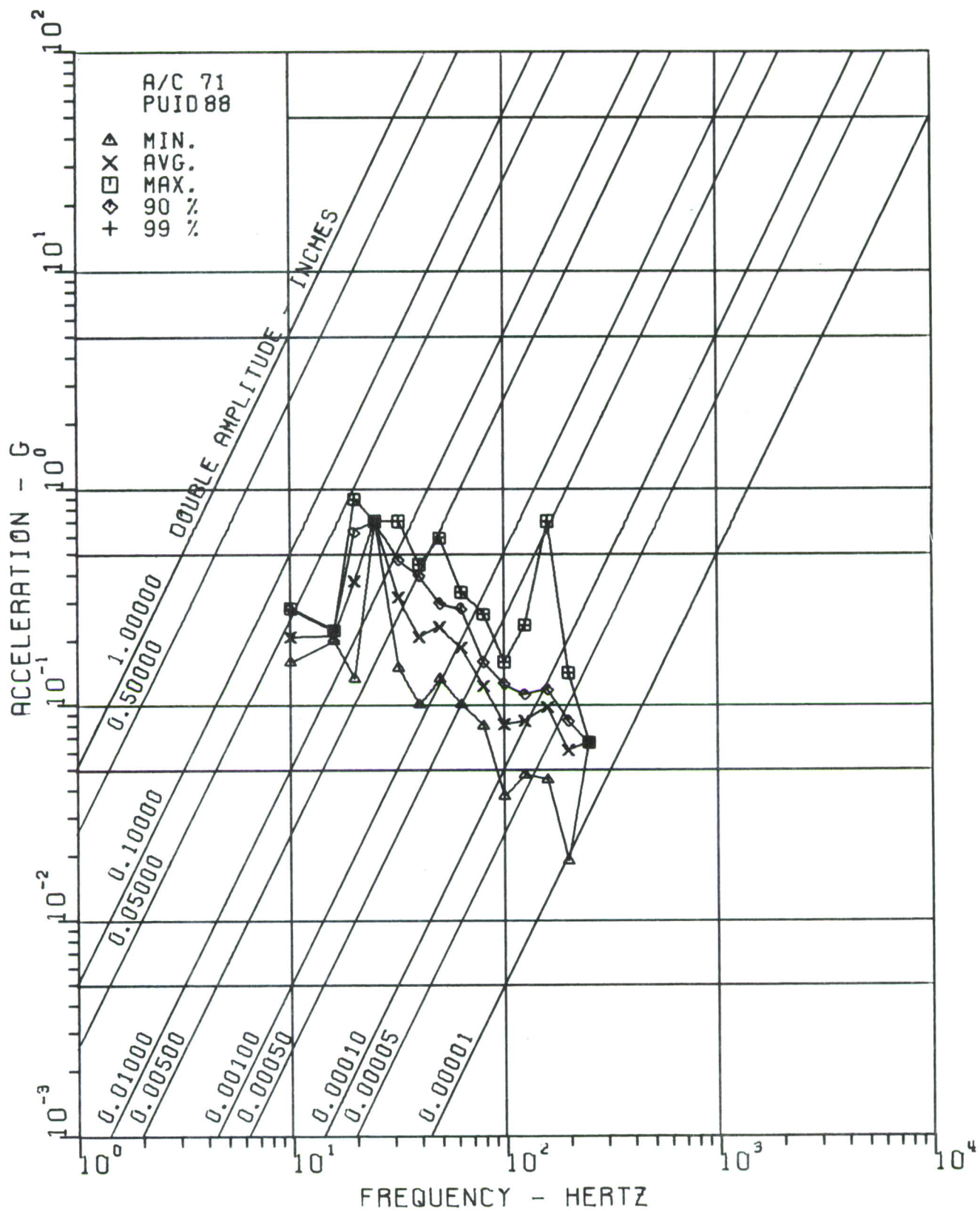


Figure 101. Pilot's Instrument Panel, Right Side, Sta. 115, with Gunfire

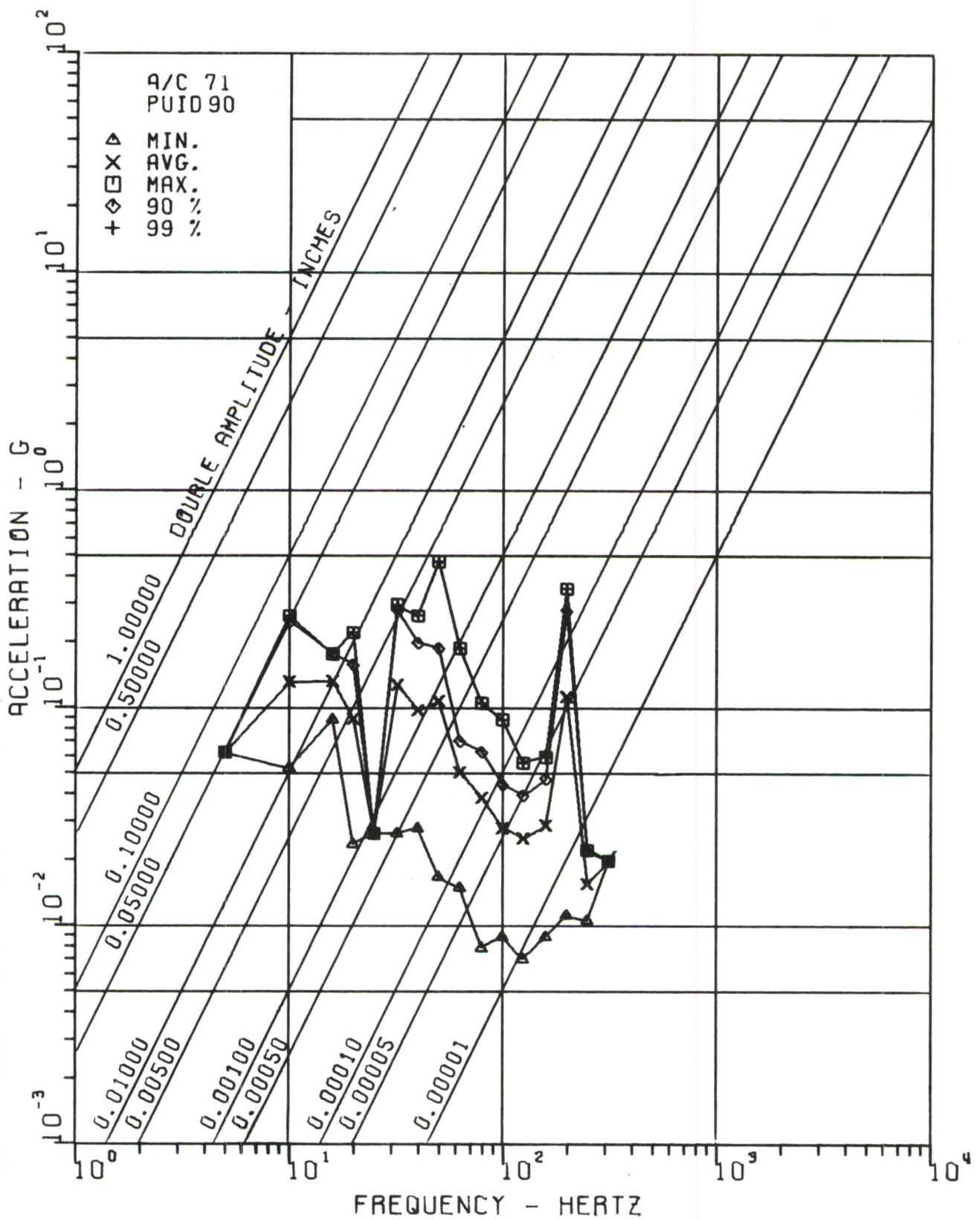


Figure 102. Pilot's Floor, Left Side, Sta. 134, without Gunfire

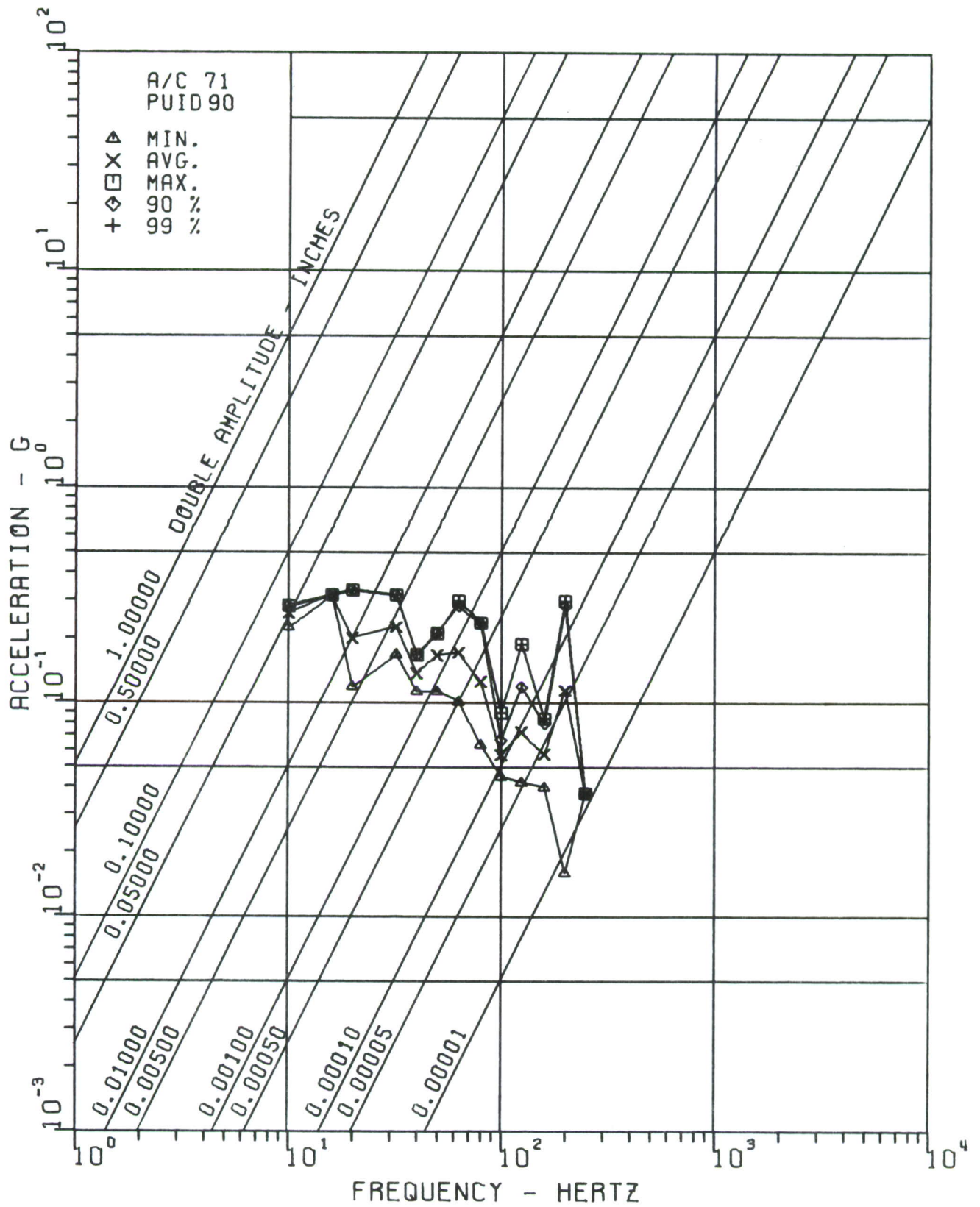


Figure 103, Pilot's Floor, Left Side, Sta. 134, with Gunfire

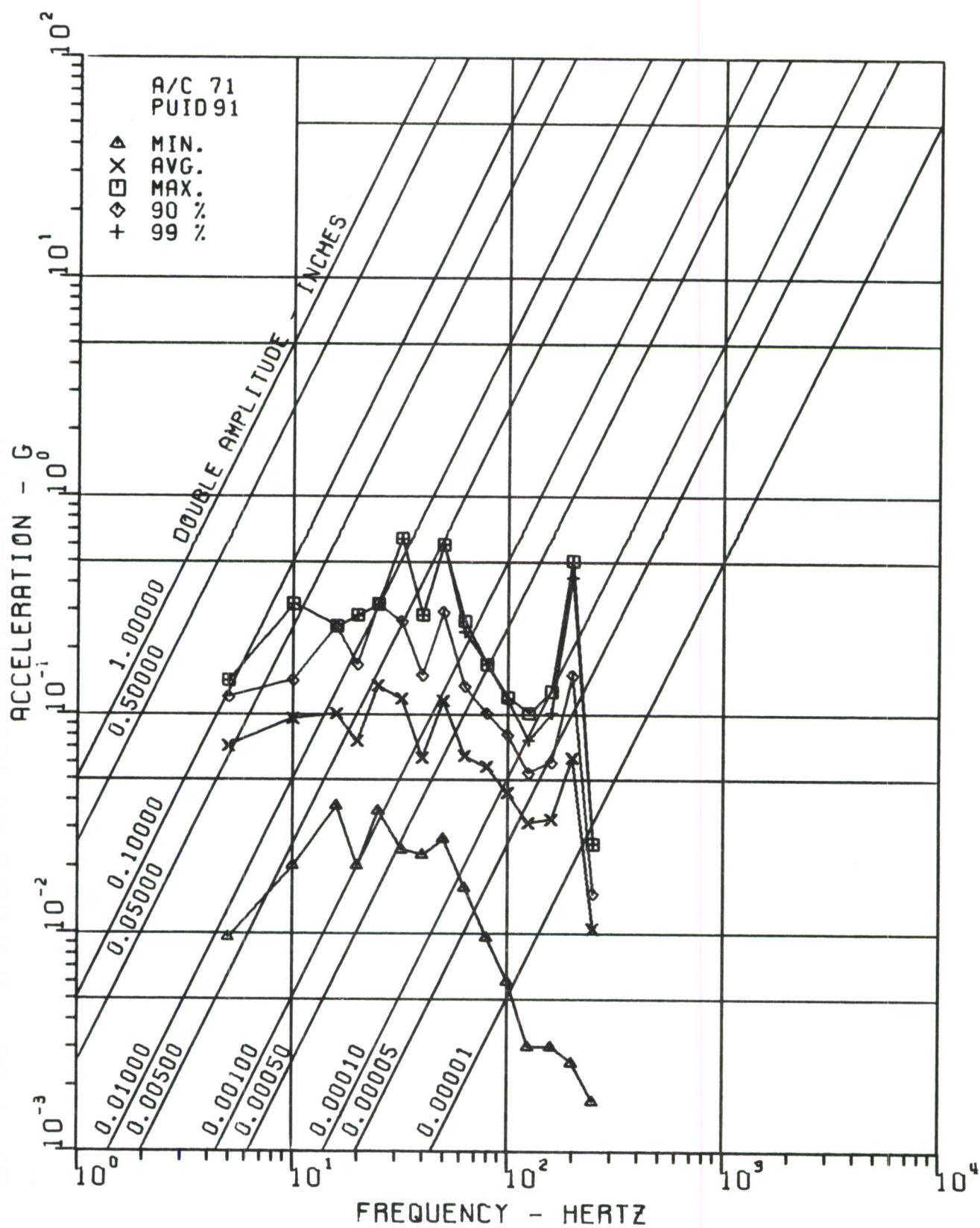


Figure 104. Pilot's Floor, Right Side, Sta. 134, without Gunfire

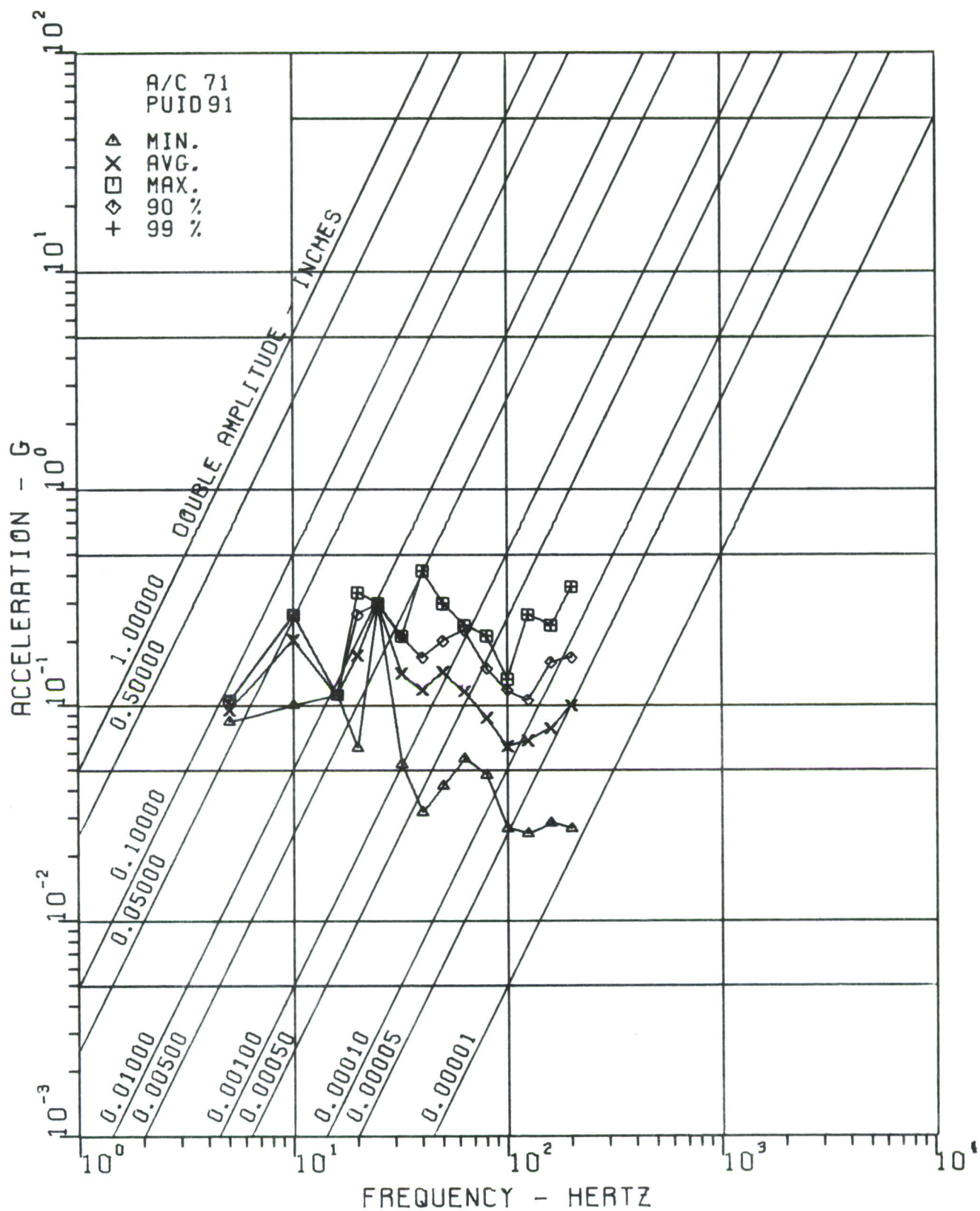


Figure 105. Pilot's Floor, Right Side, Sta. 134, with Gunfire

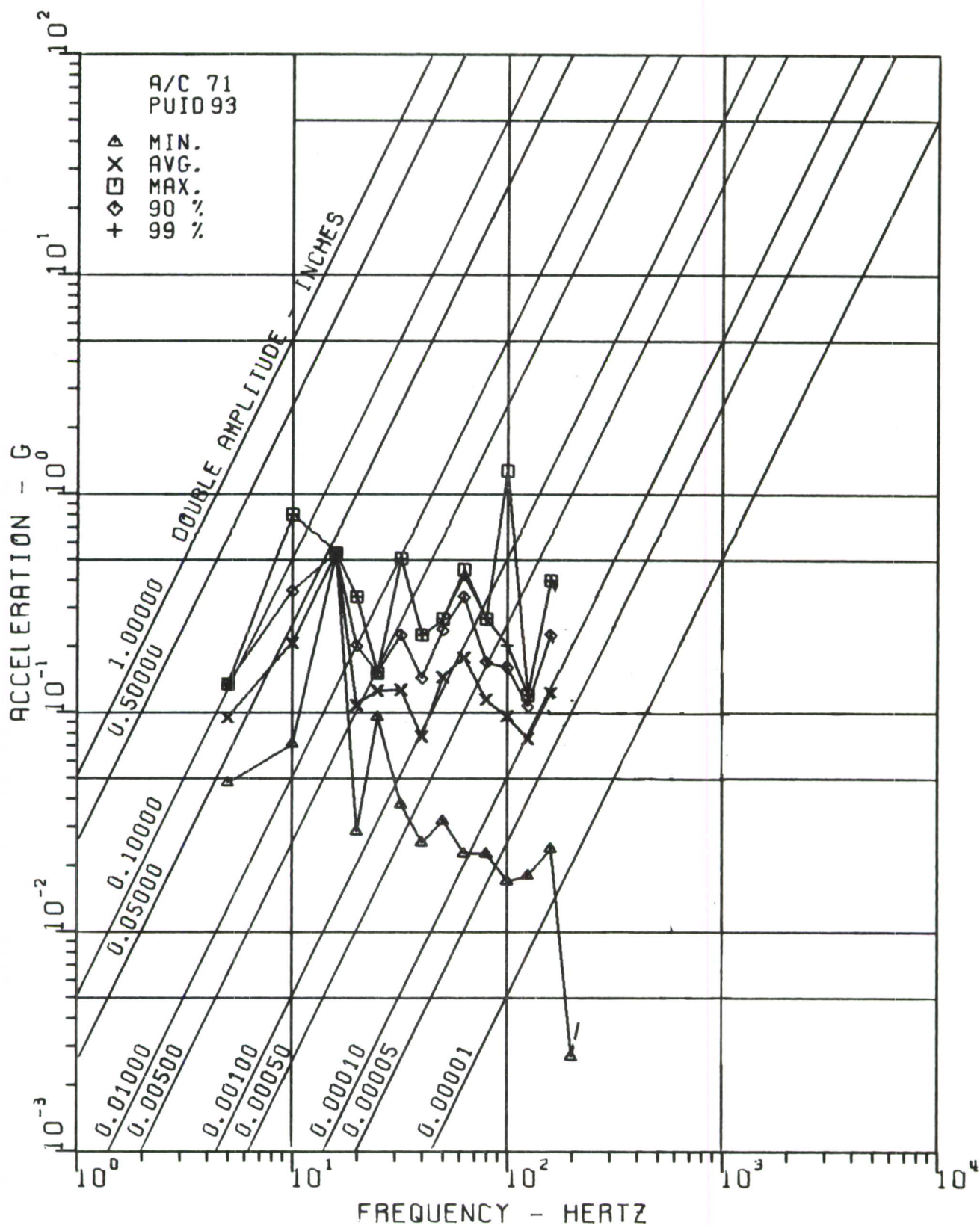


Figure 106. Aft Electrical Comp. near AN/ASN-43 Gyro Compass, Sta. 284,
without Gunfire

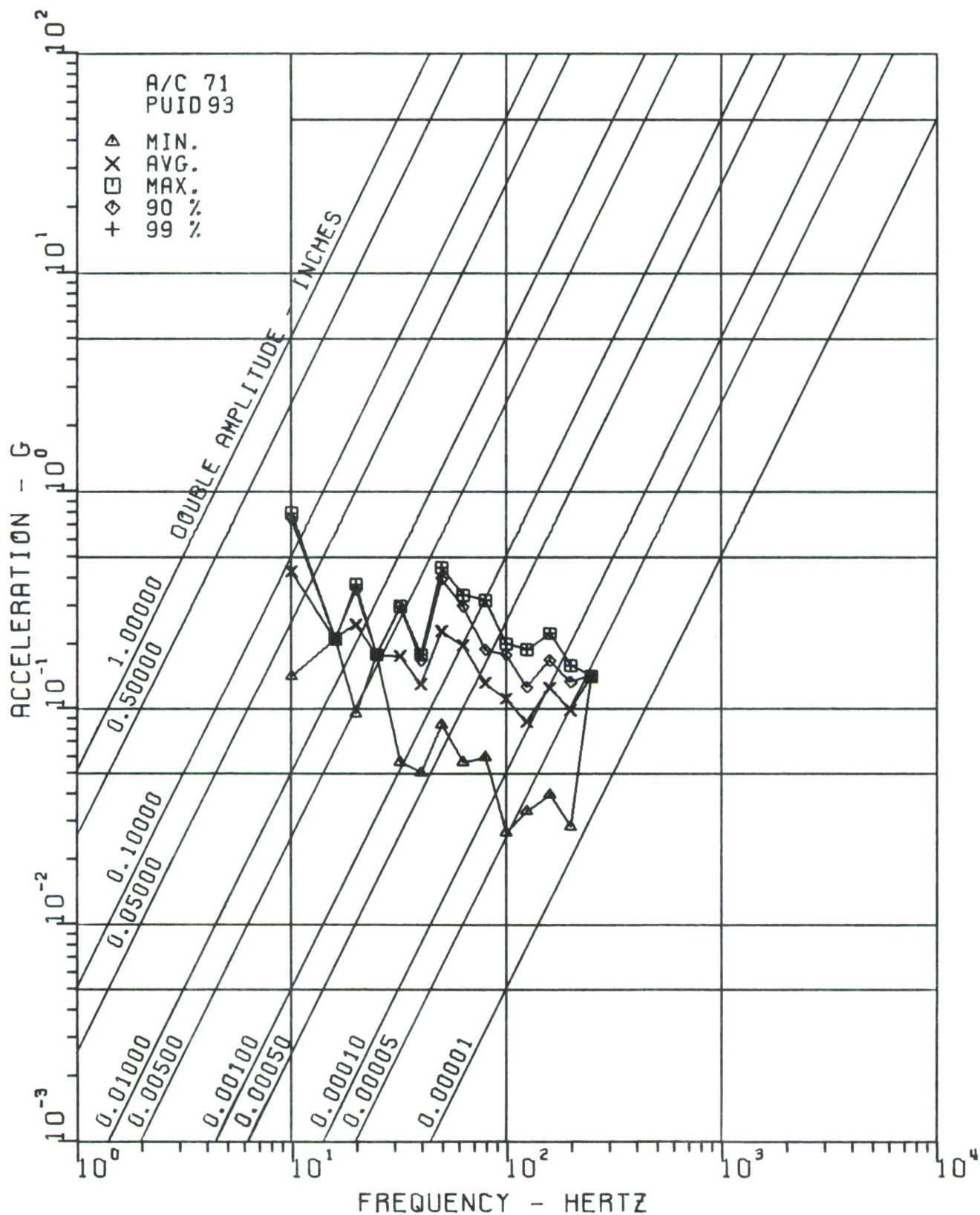


Figure 107. Aft Electrical Compartment near AN/ASN-43 Gyro Compass,
Sta. 284, with Gunfire

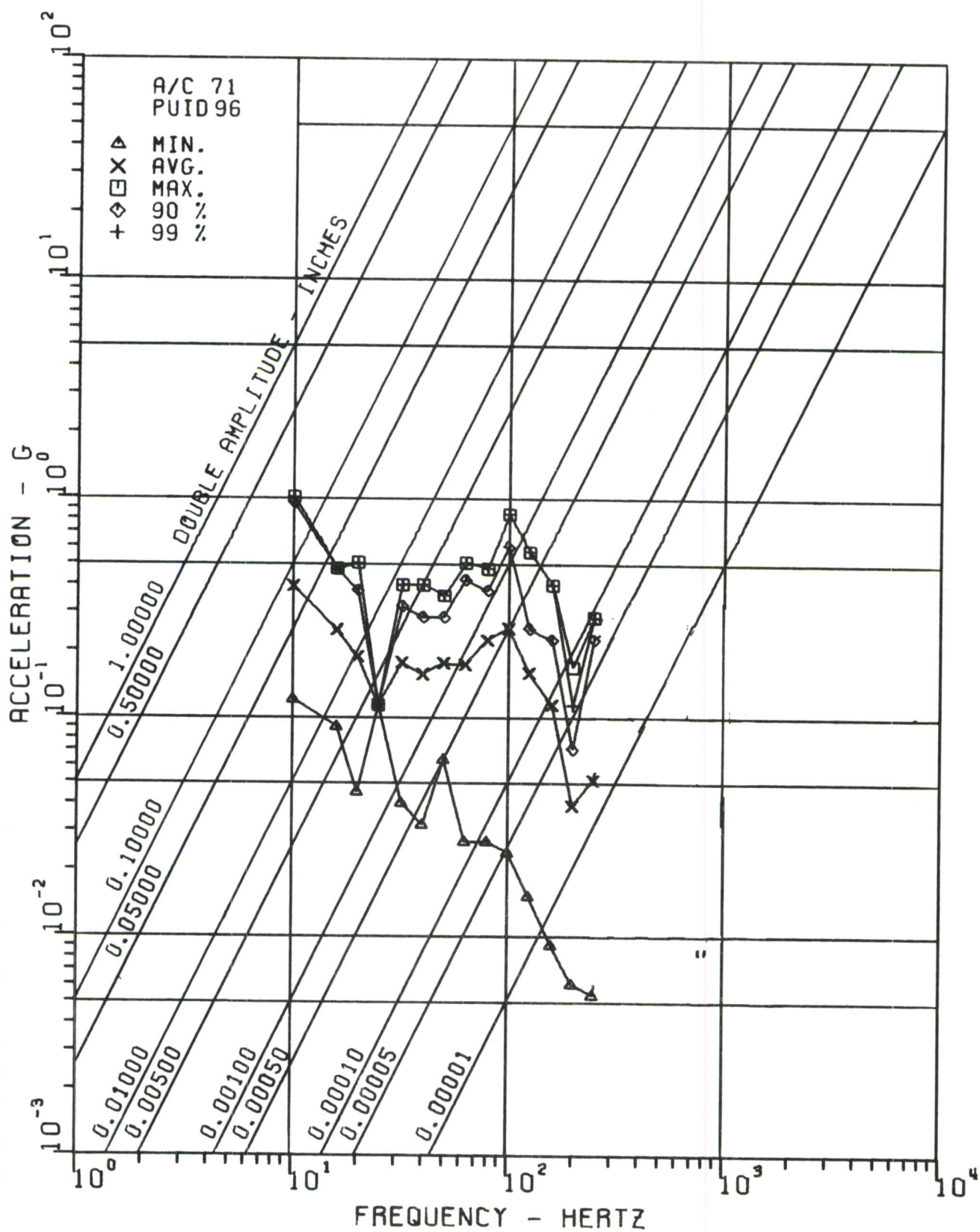


Figure 108. Tail Boom near 90° Gear Box, Sta. 524, without Gunfire

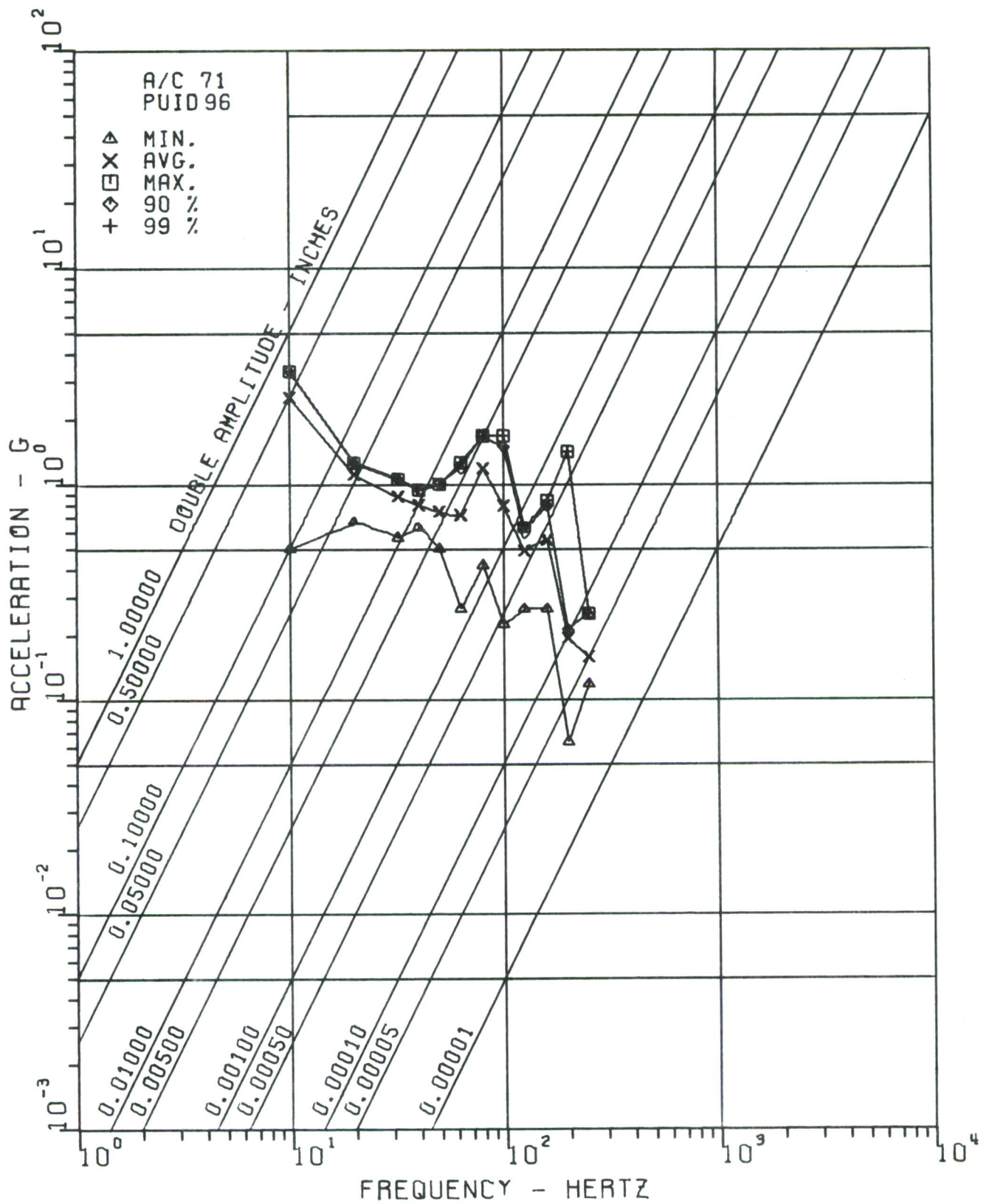


Figure 109. Tail Boom near 90° Gear Box, Sta. 524, with Gunfire

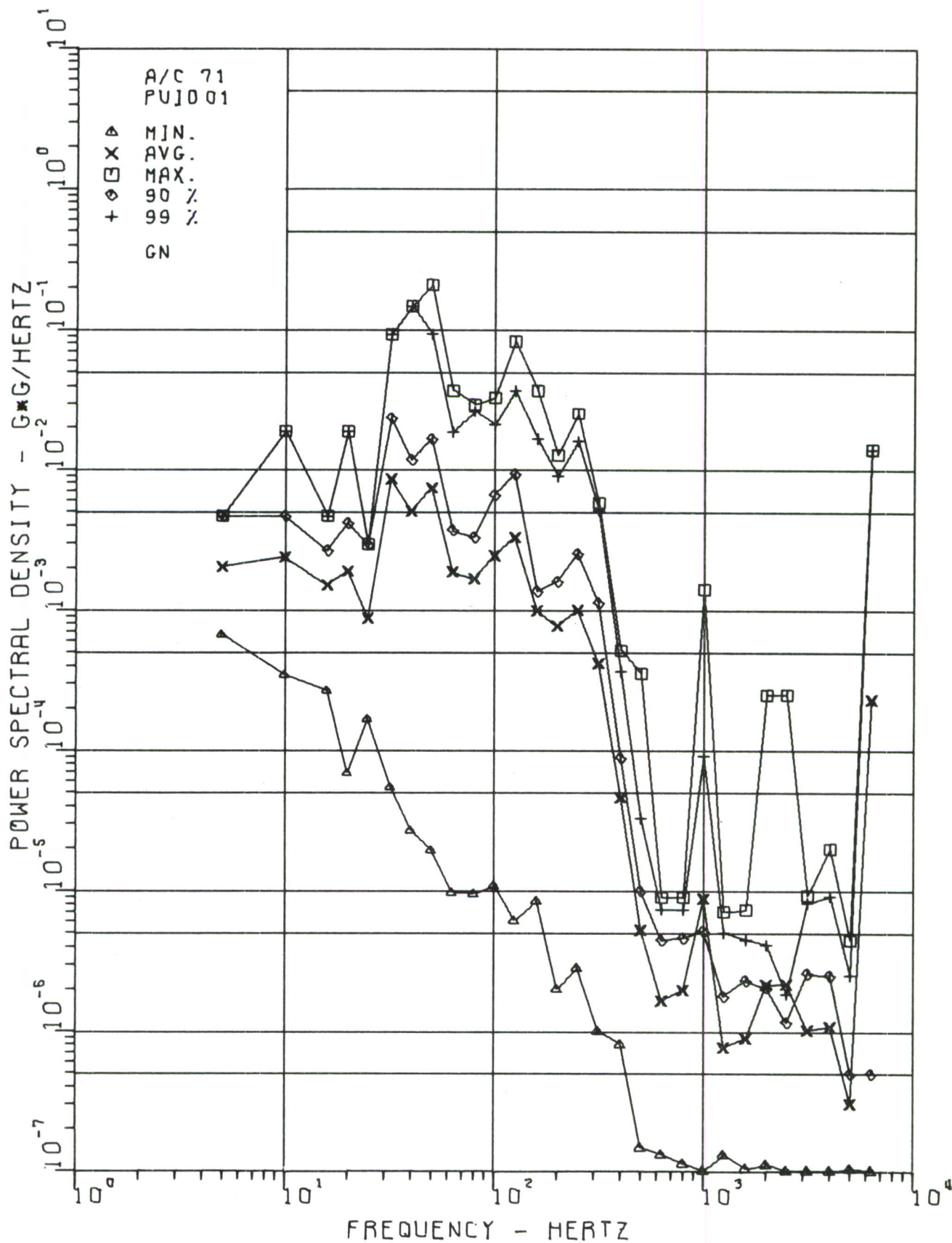


Figure 110. Gunner's Instrument Panel, Left Side, Sta. 60

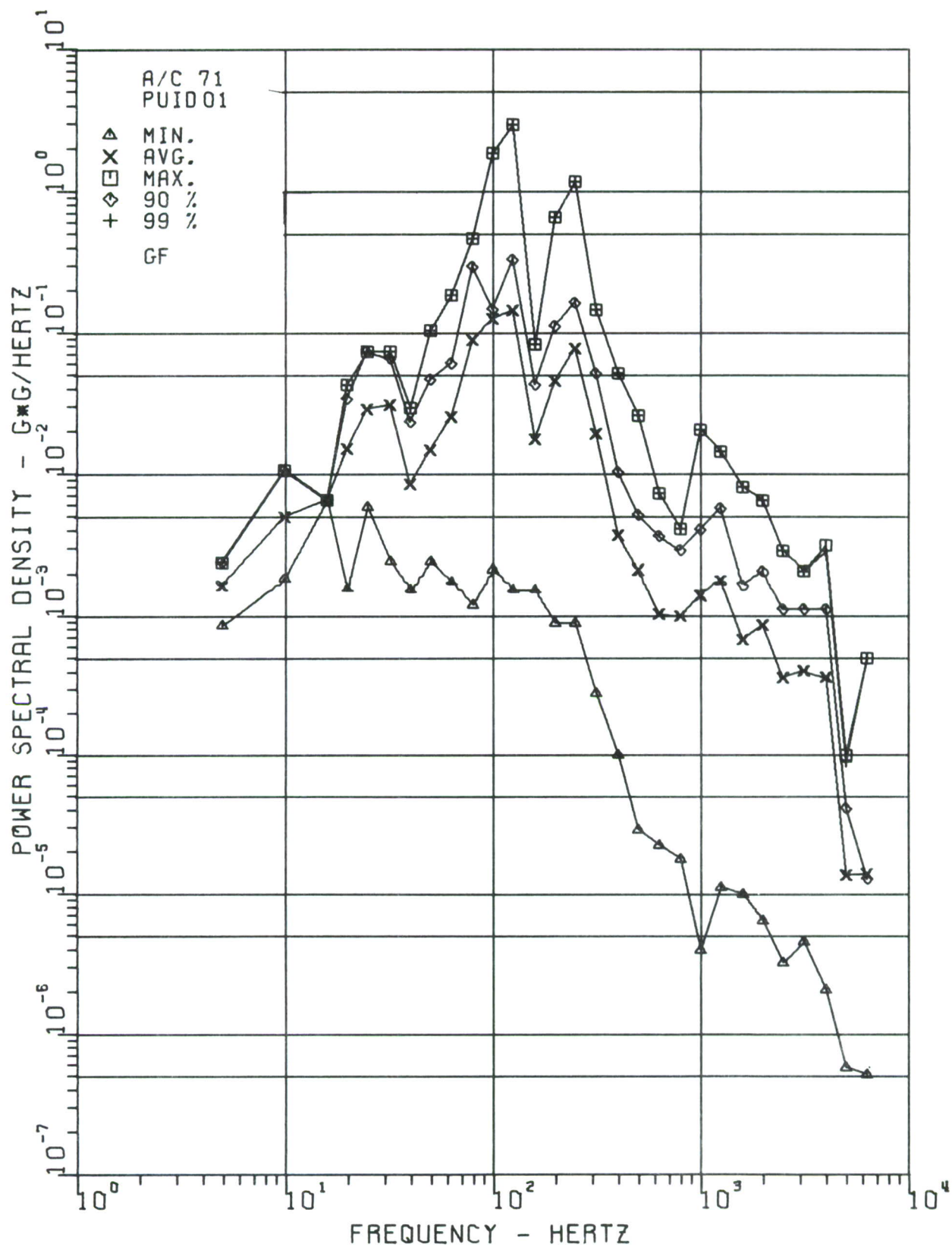


Figure 111. Gunner's Instrument Panel, Left Side, Sta. 60,
with Gunfire

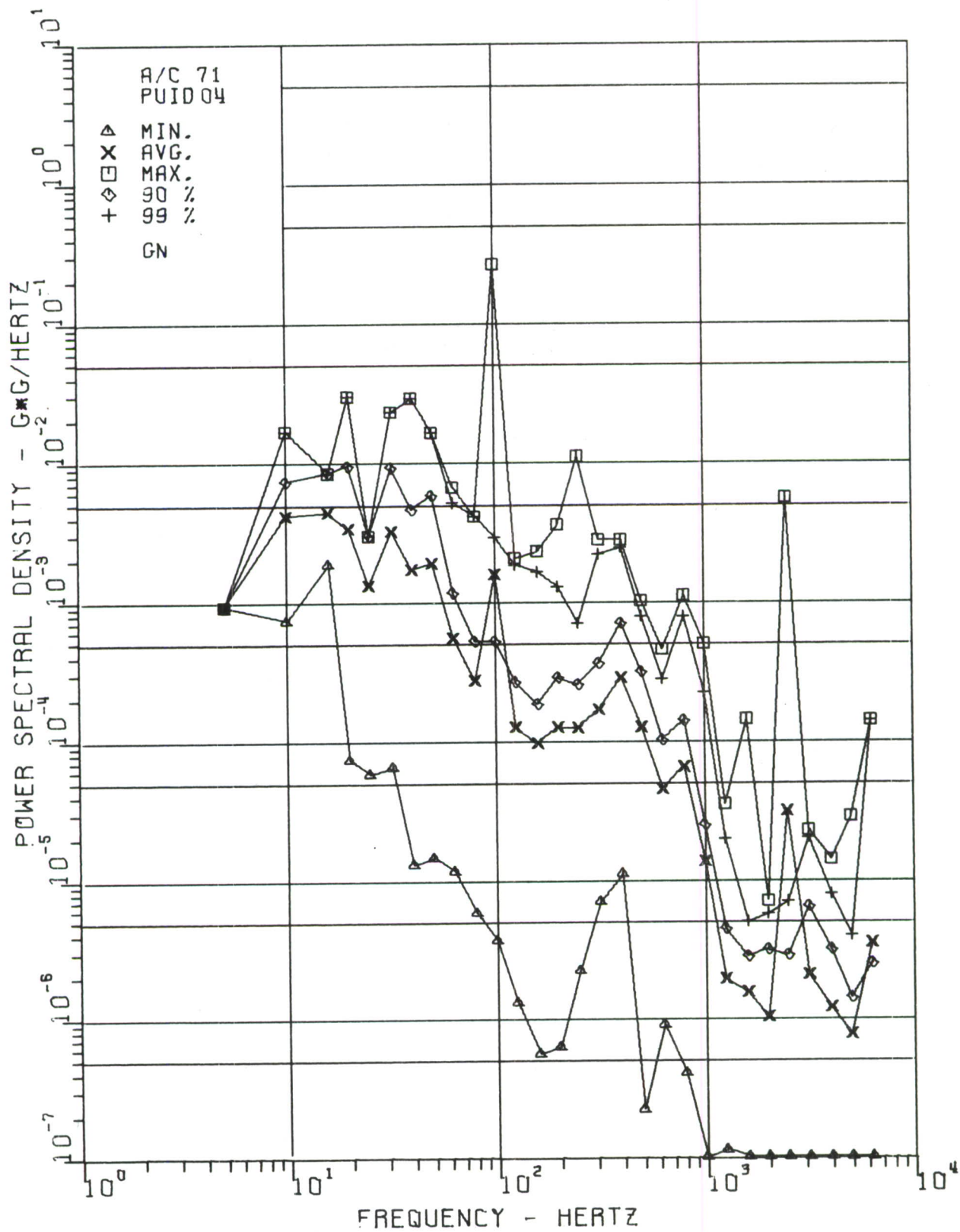


Figure 112. Gunner's Pedestal, Left Side, Sta. 65

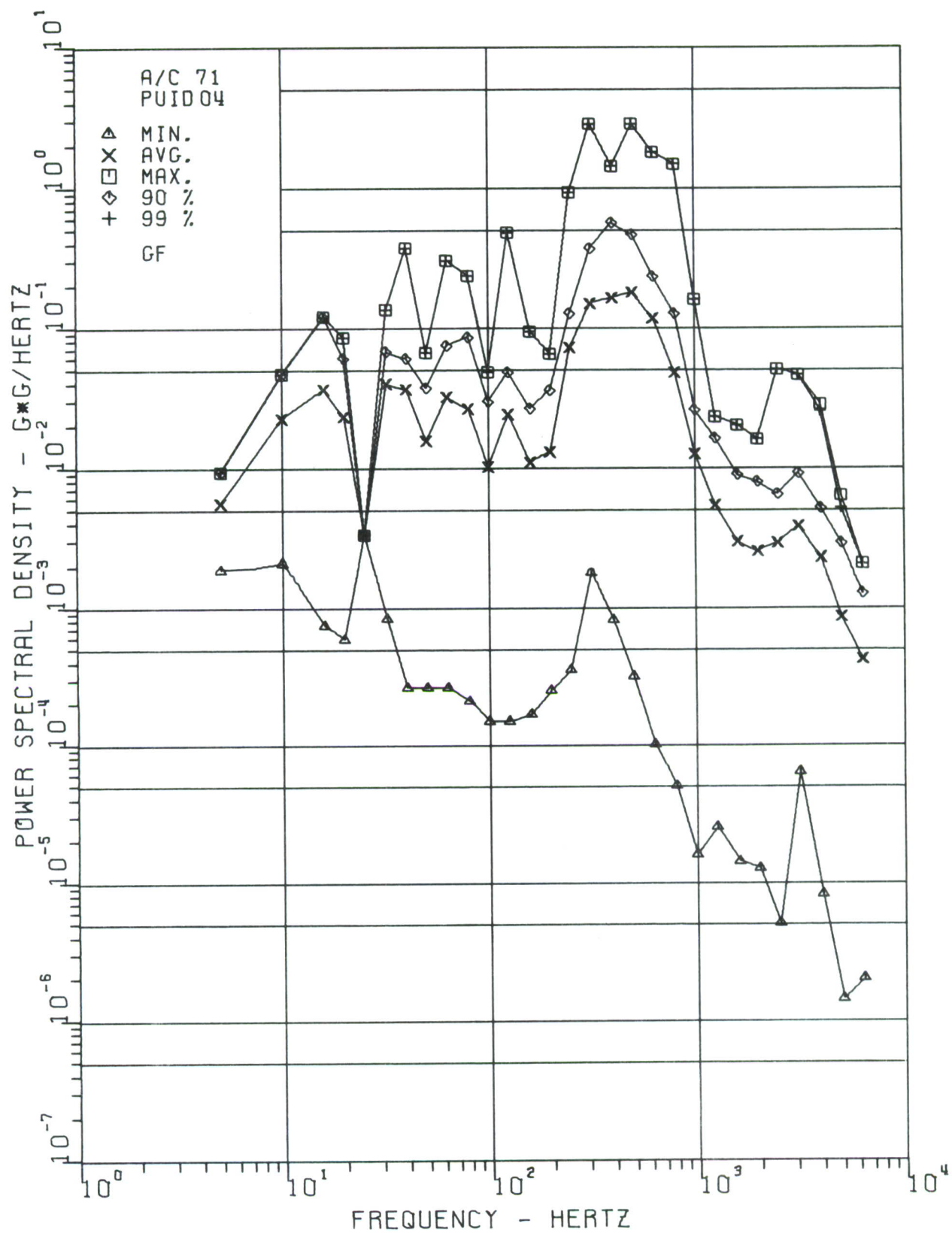


Figure 113. Gunner's Pedestal, Left Side, Sta. 65, with Gunfire

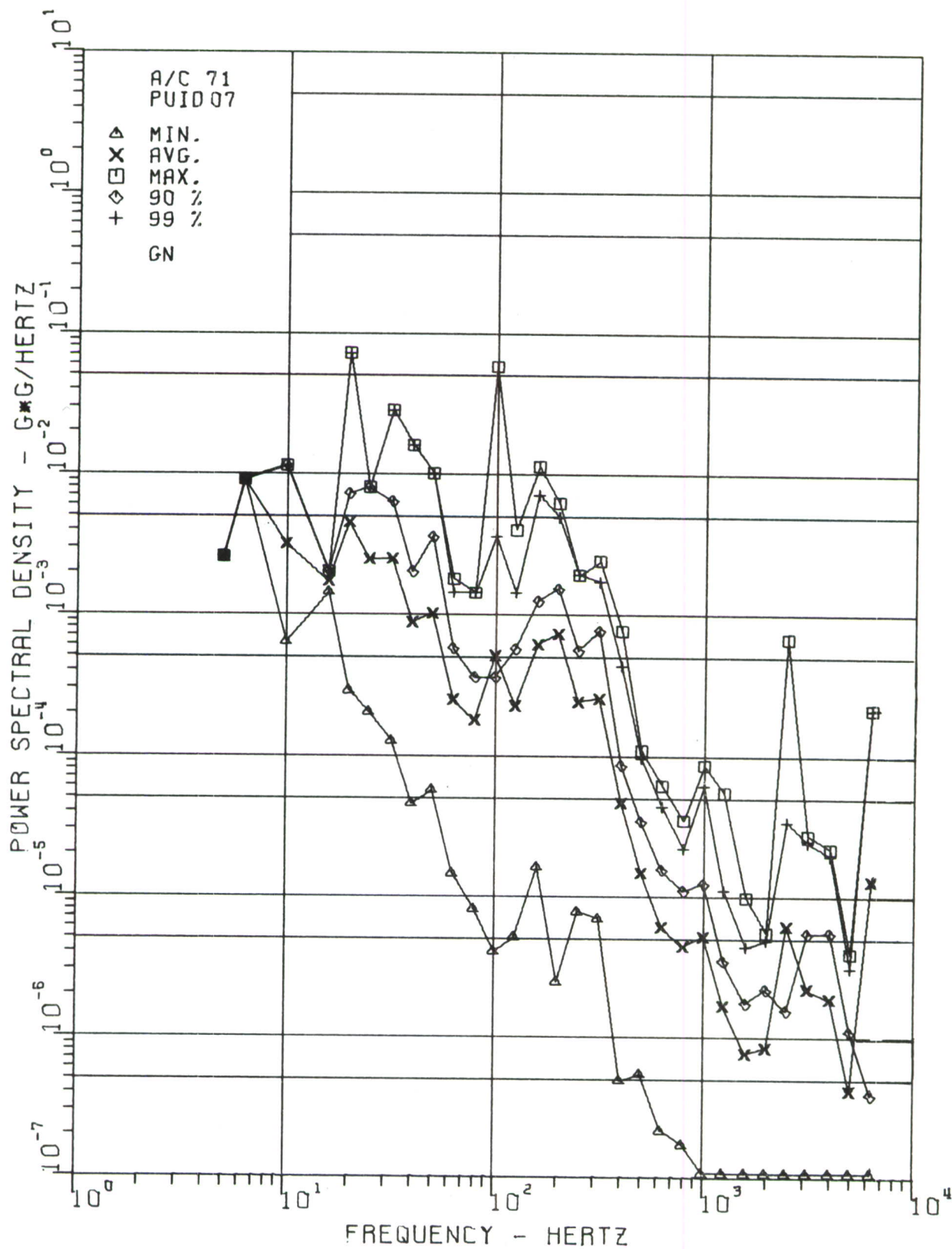


Figure 114. Gunner's Pedestal, Right Side, Sta. 77 without Gunfire

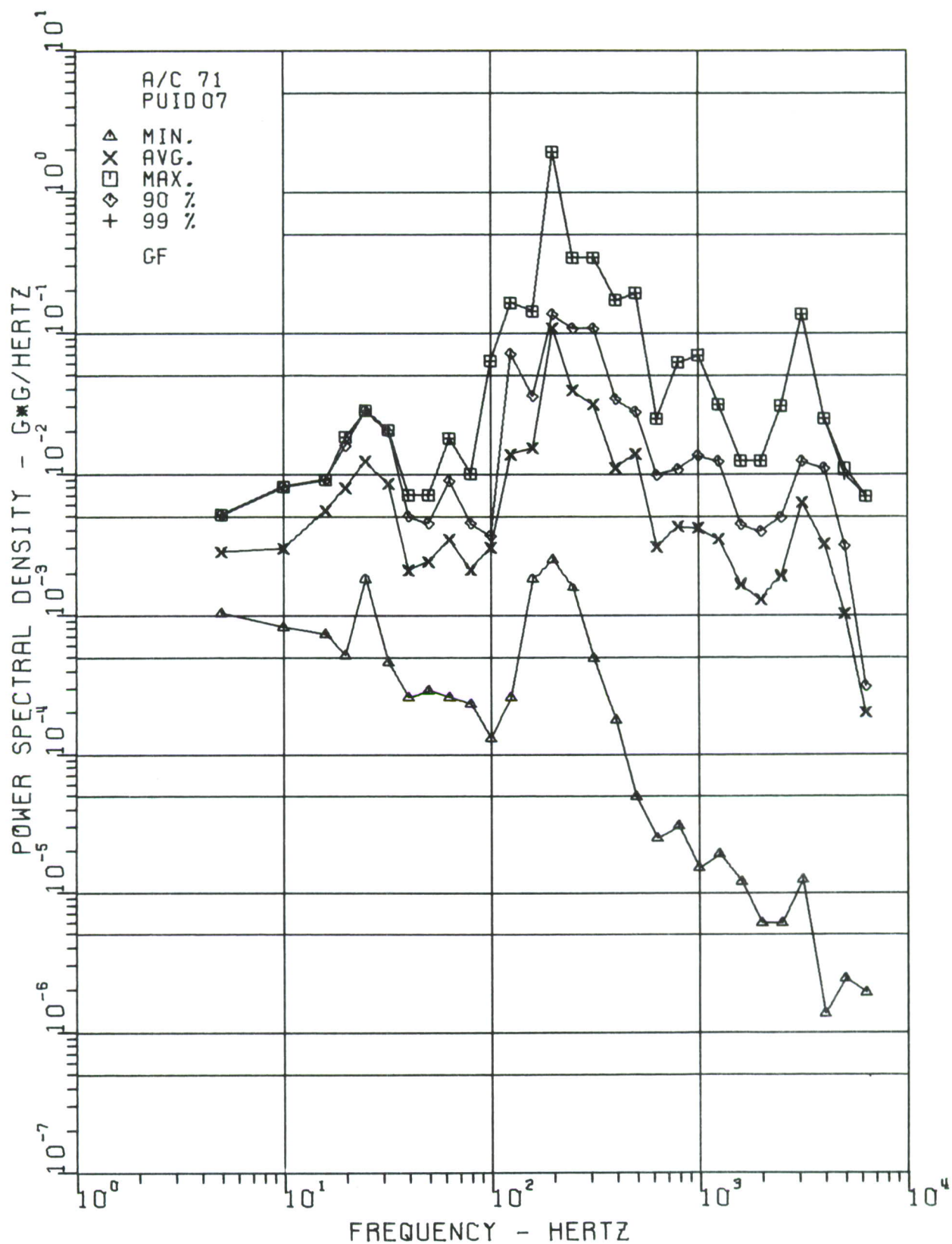


Figure 115. Gunner's Pedestal, Left Side, Sta. 65, with Gunfire

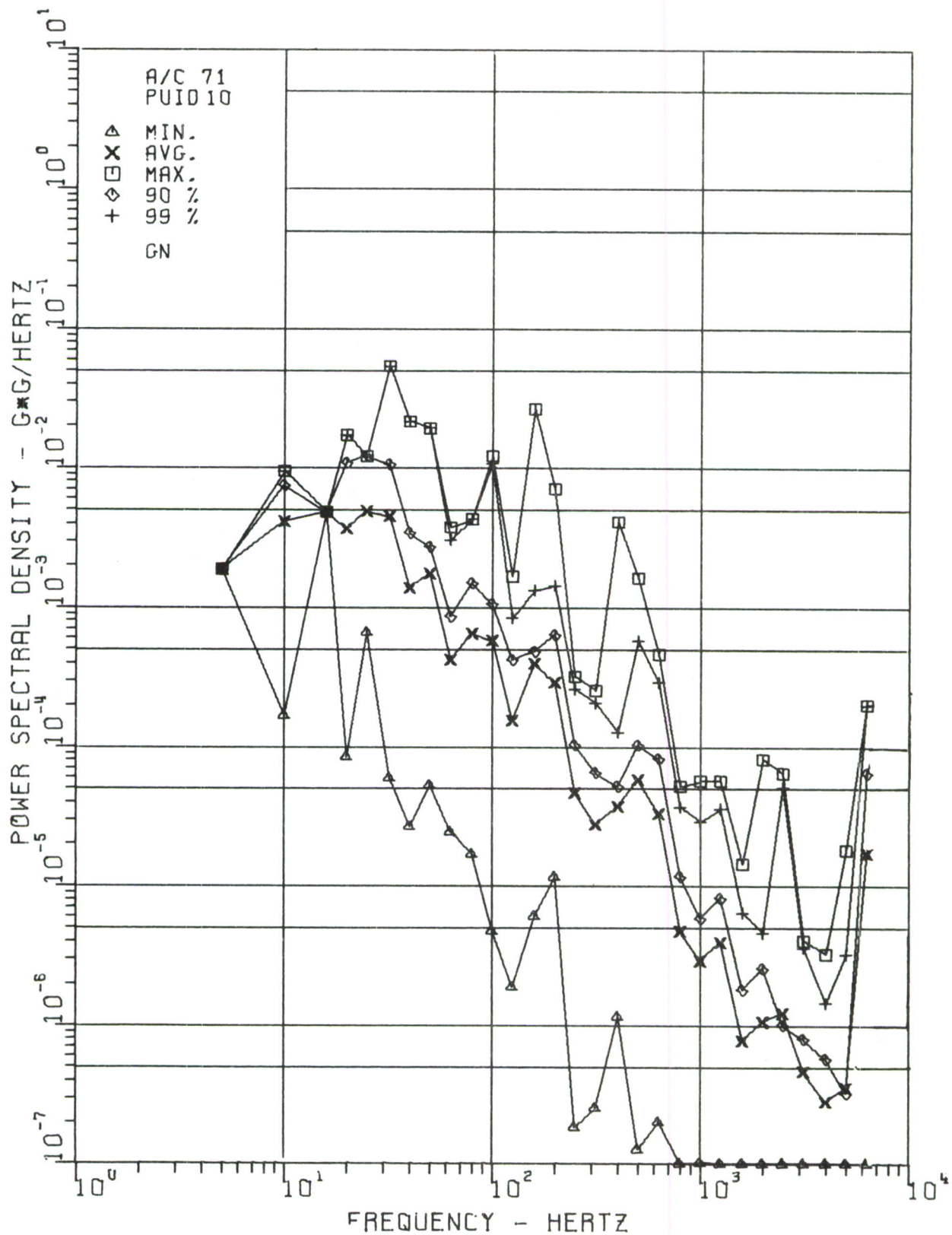


Figure 116. Gunner's Instrument Comp., Right Side, Sta. 73 without Gunfire

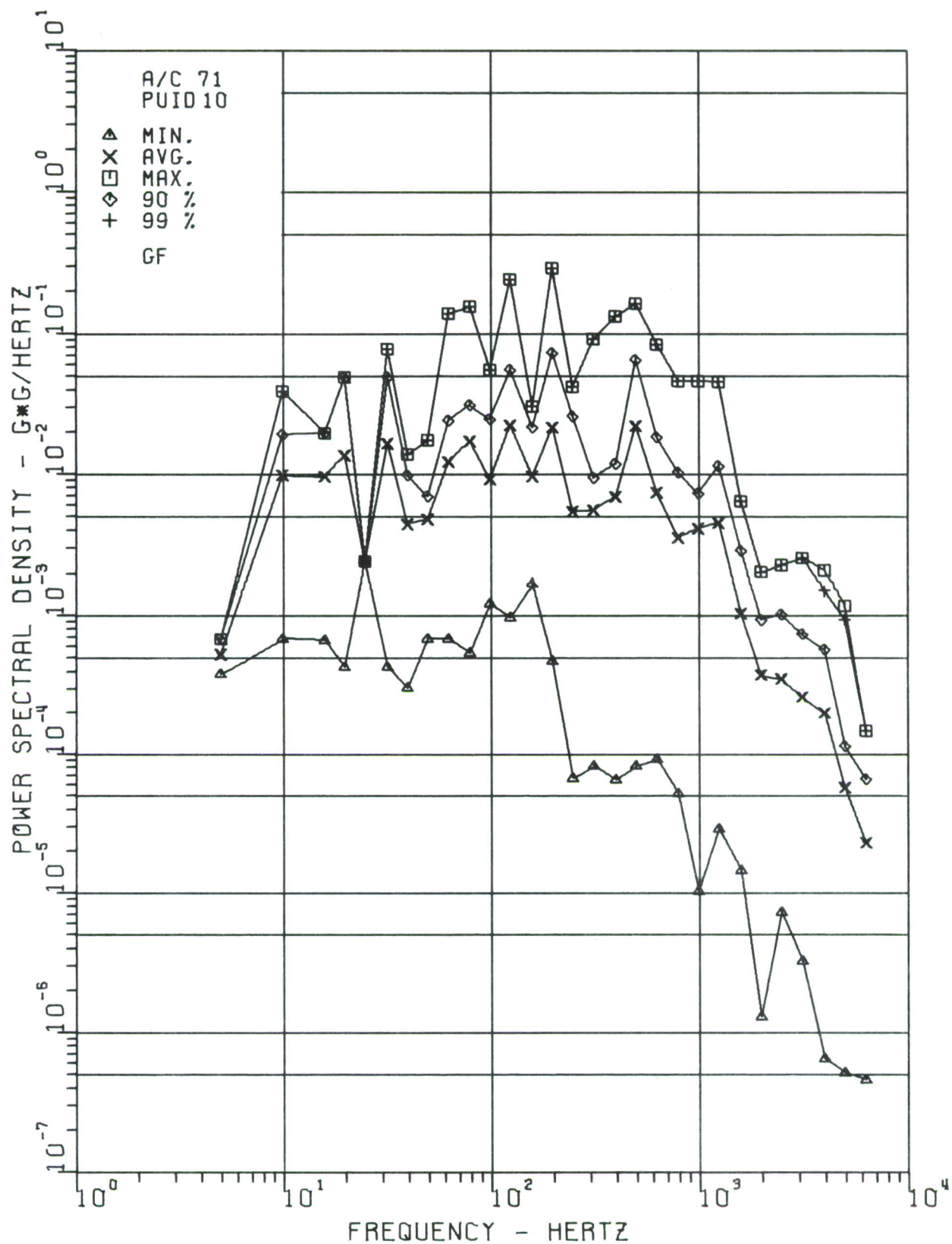


Figure 117. Gunner's Instrument Comp., Right Side, Sta. 73
 with Gunfire

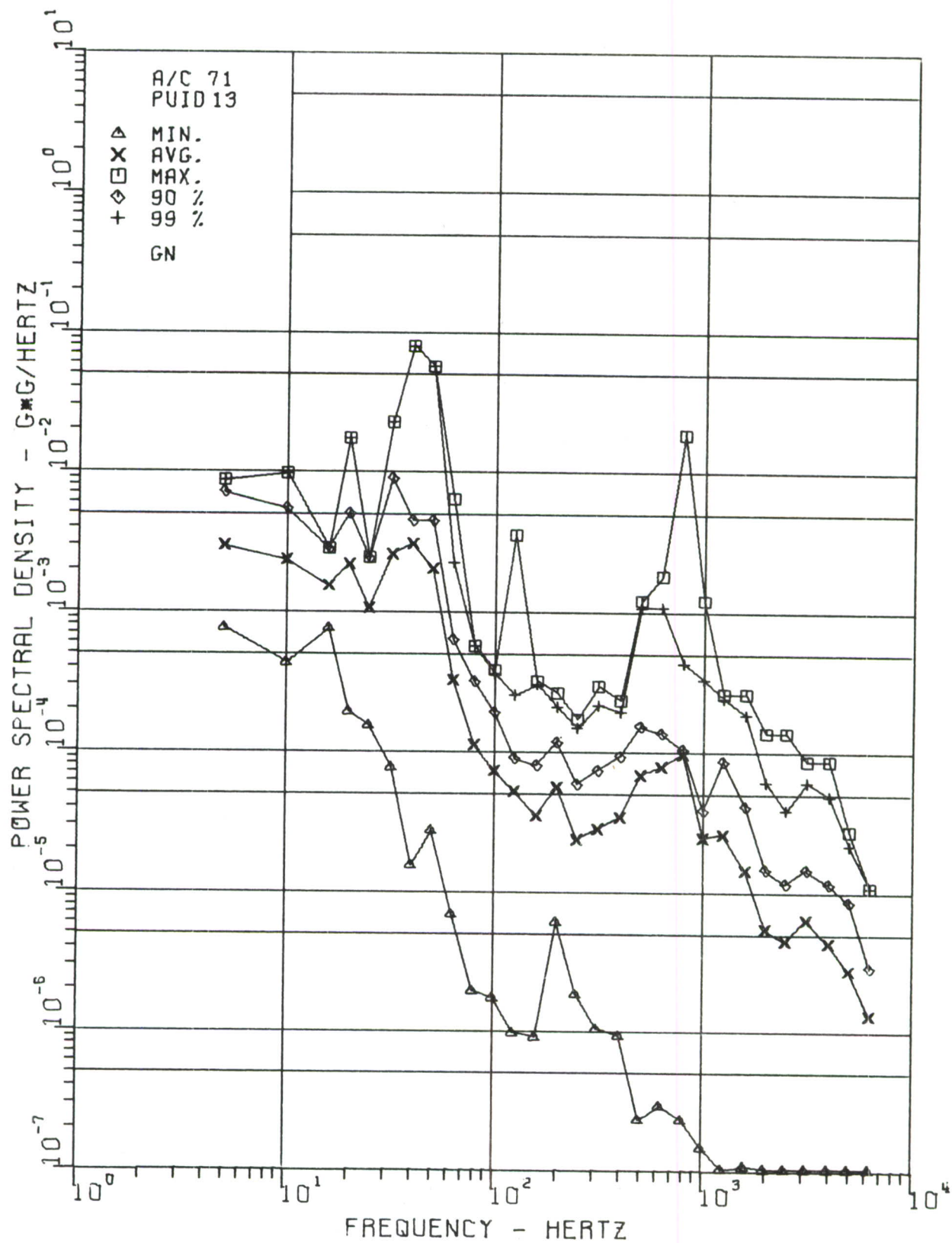


Figure 118. Gunner's Floor, Center, Sta. 66

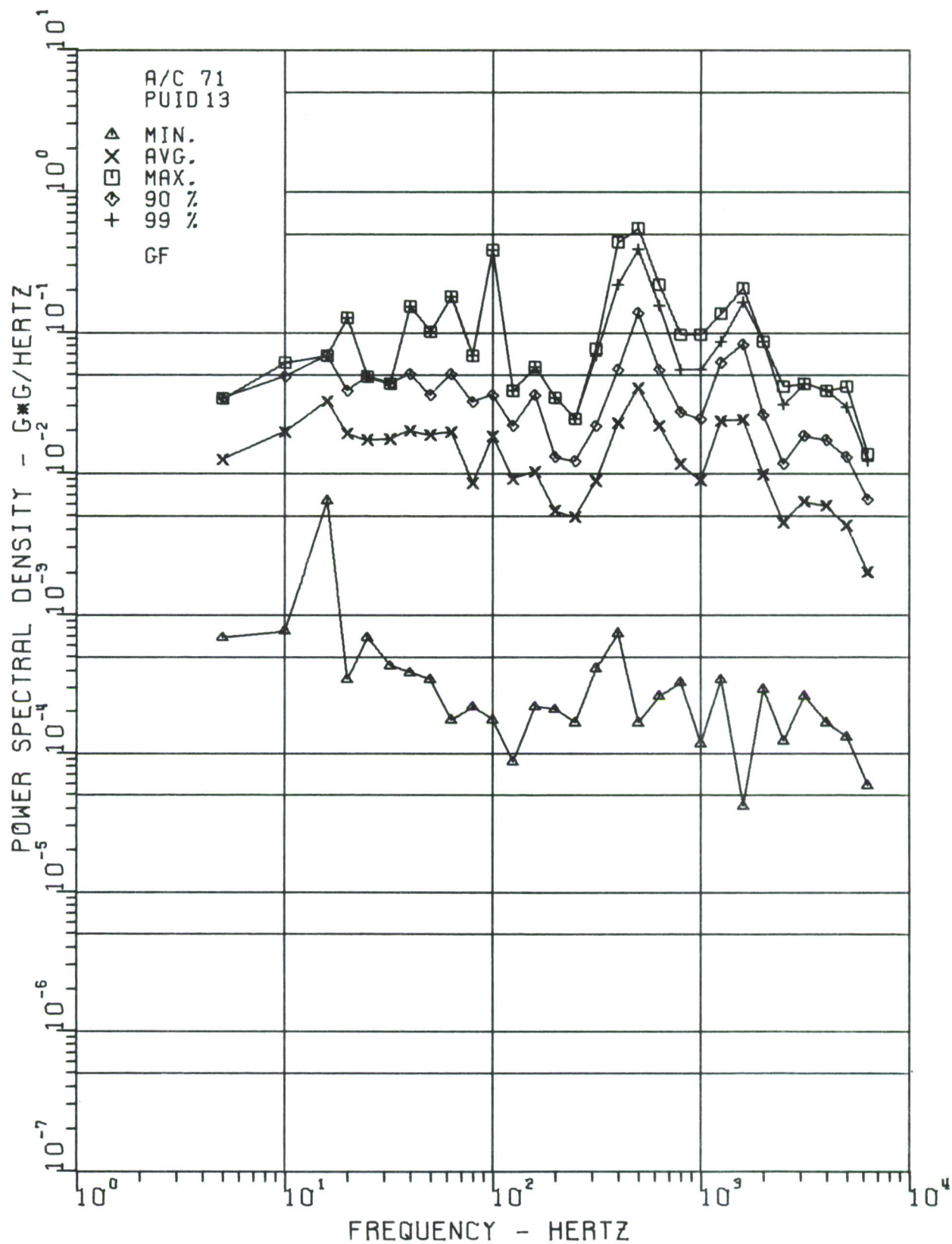


Figure 119. Gunner's Floor, Center, Sta. 66, with Gunfire

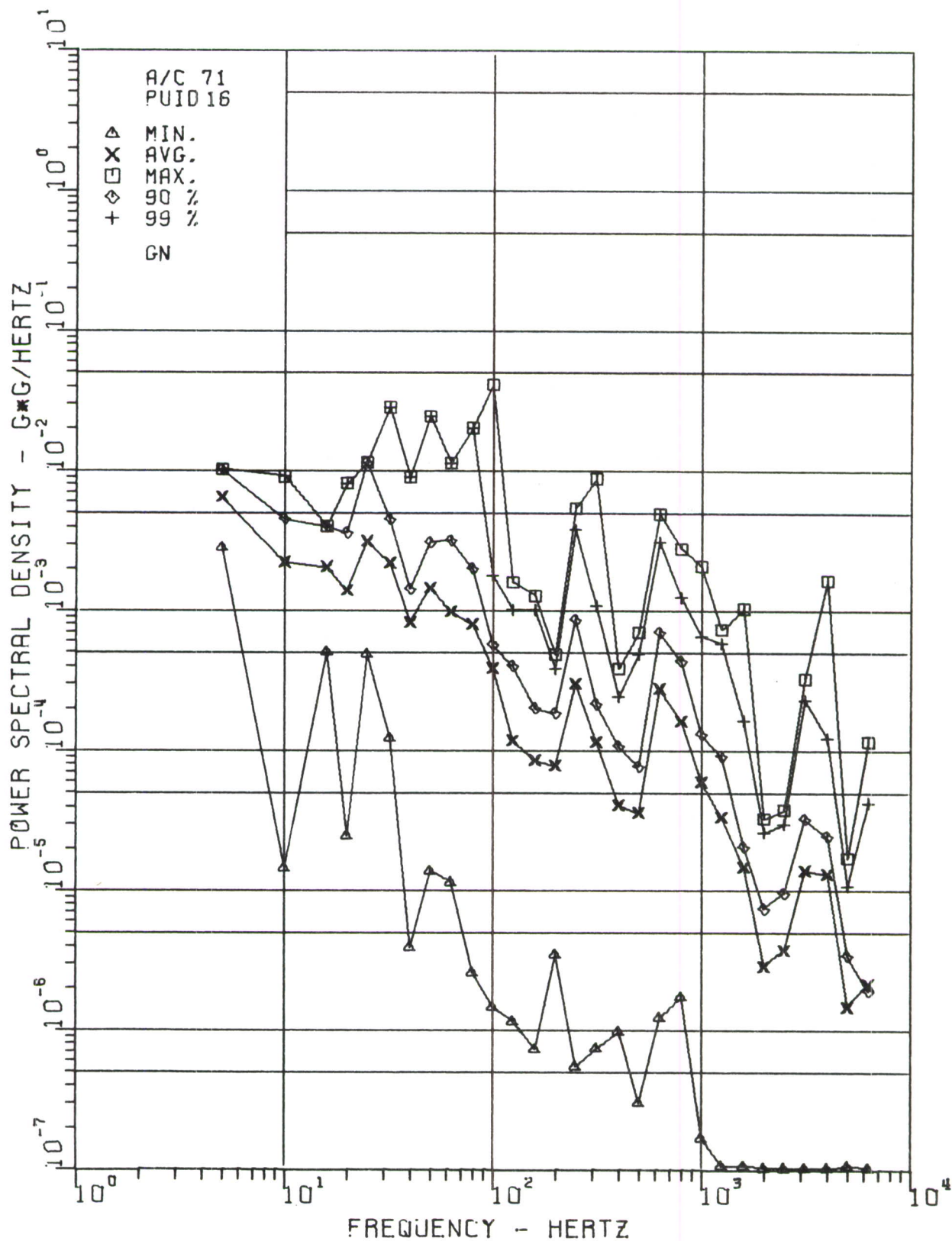


Figure 120. XM-28 Turret Interface, Sta. 69

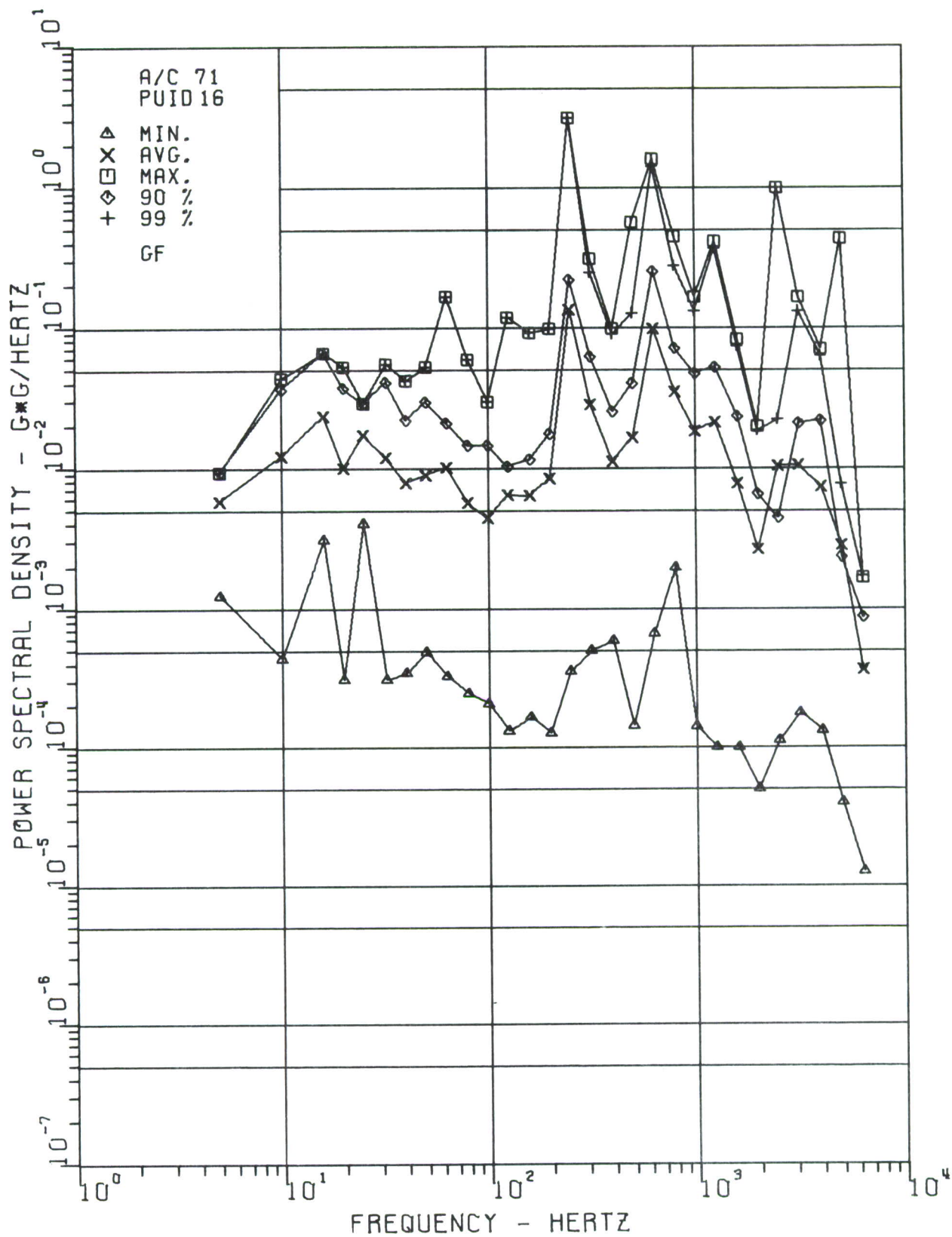


Figure 121. XM-28 Turret Interface, Sta. 69, with Gunfire

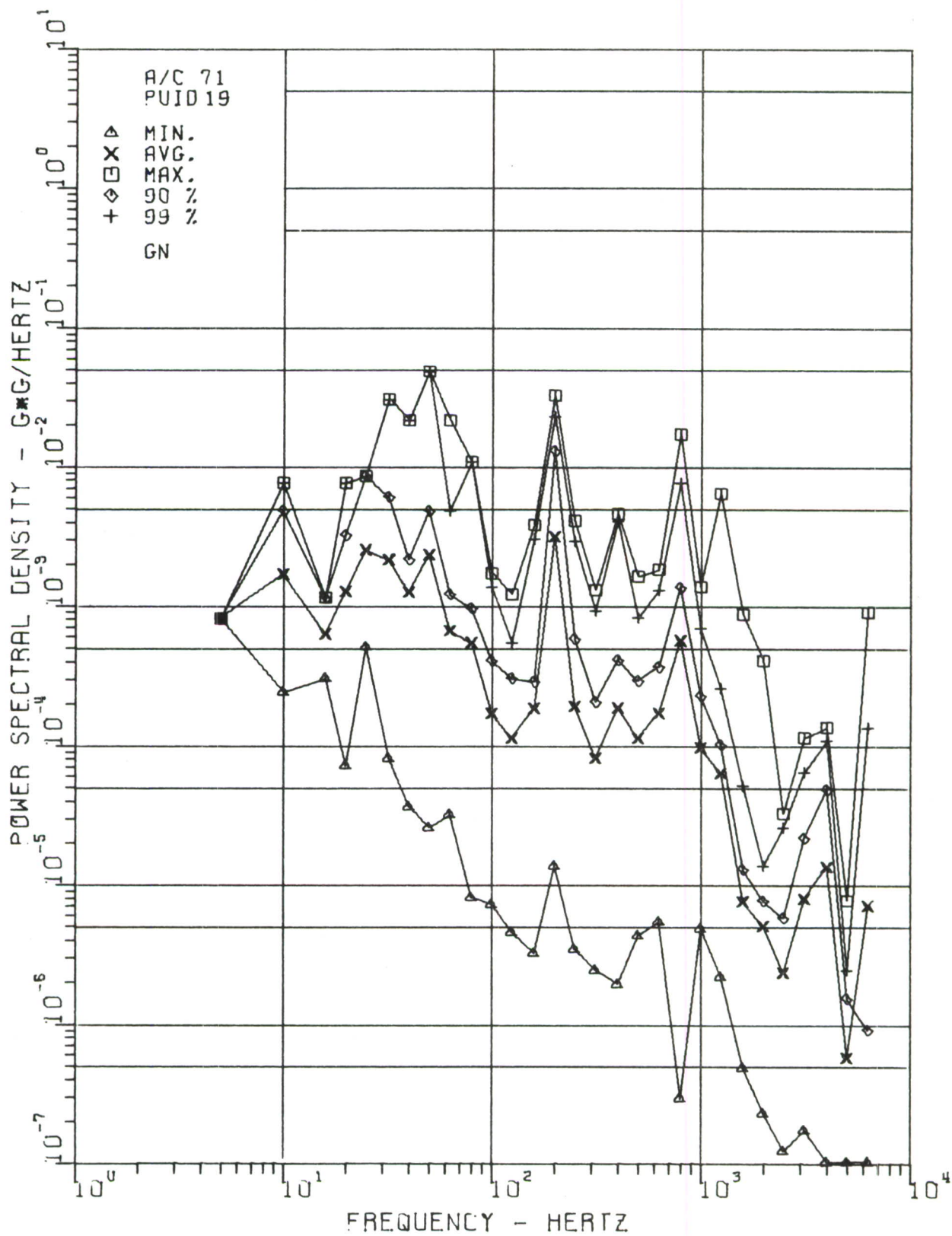


Figure 122. Pilot's Floor, Center, Sta. 134

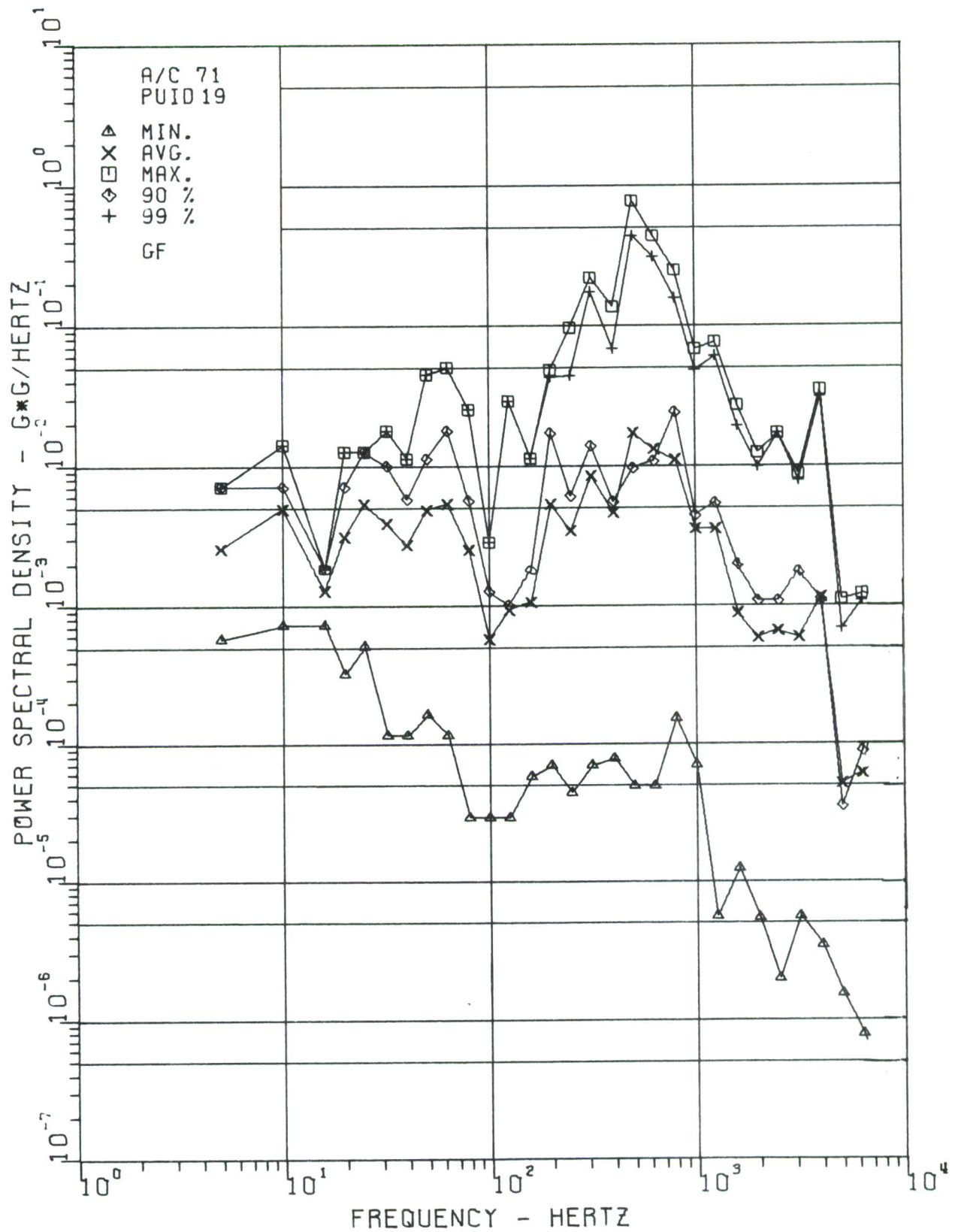


Figure 123. Pilot's Floor, Center, Sta. 134, with Gunfire

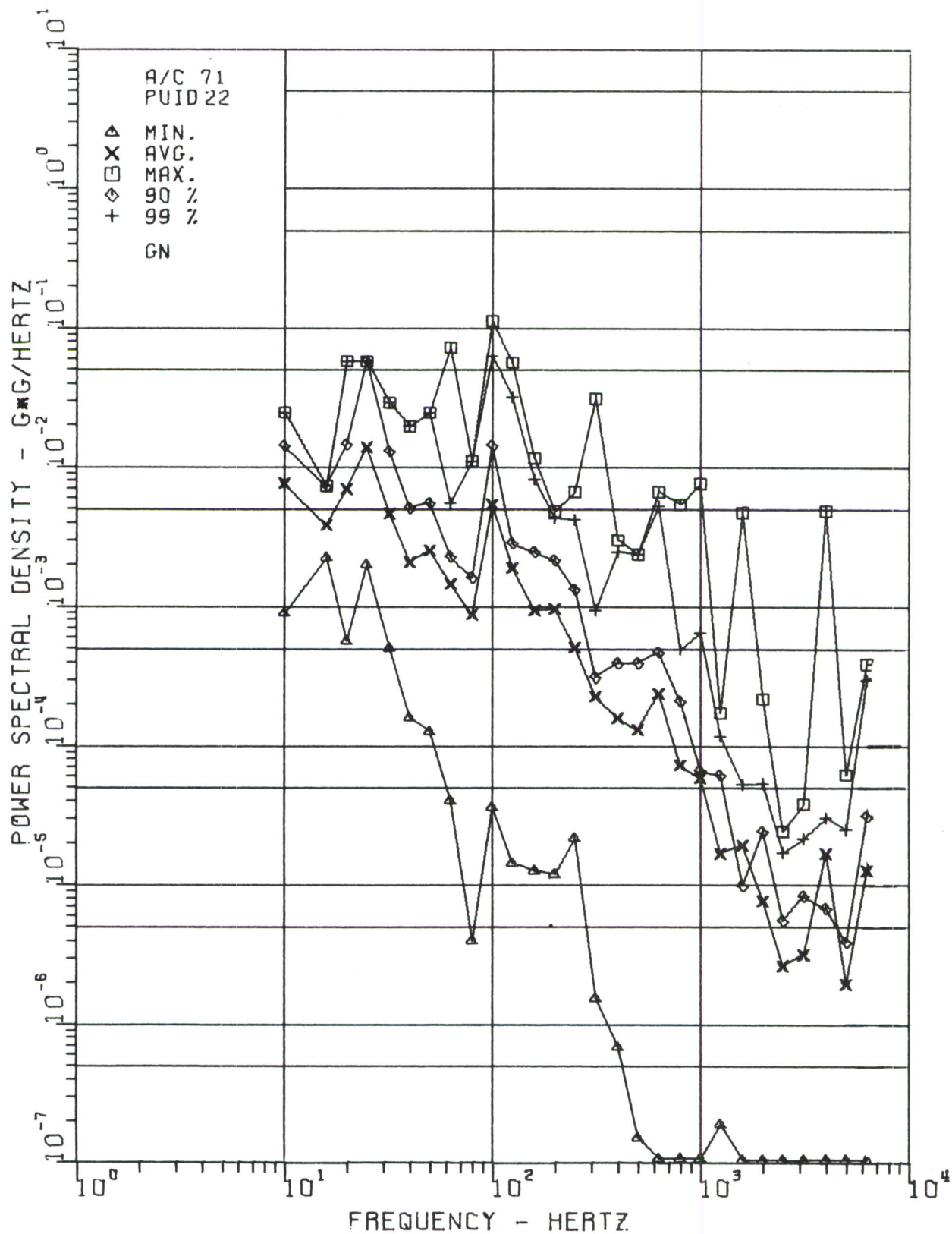


Figure 124. XM-28 Turret, Center, Sta. 77

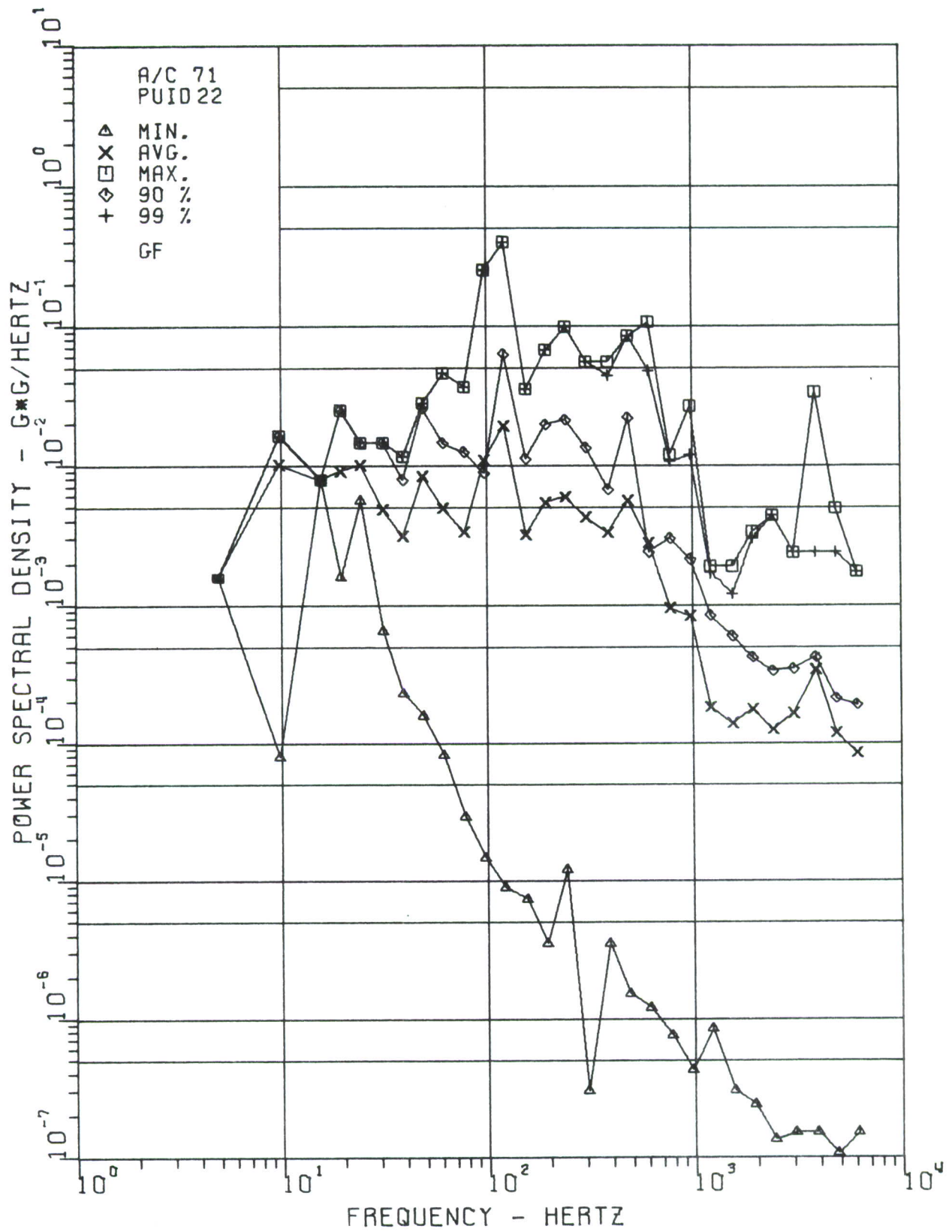


Figure 125. XM-28 Turret, Center, Sta. 77, with Gunfire

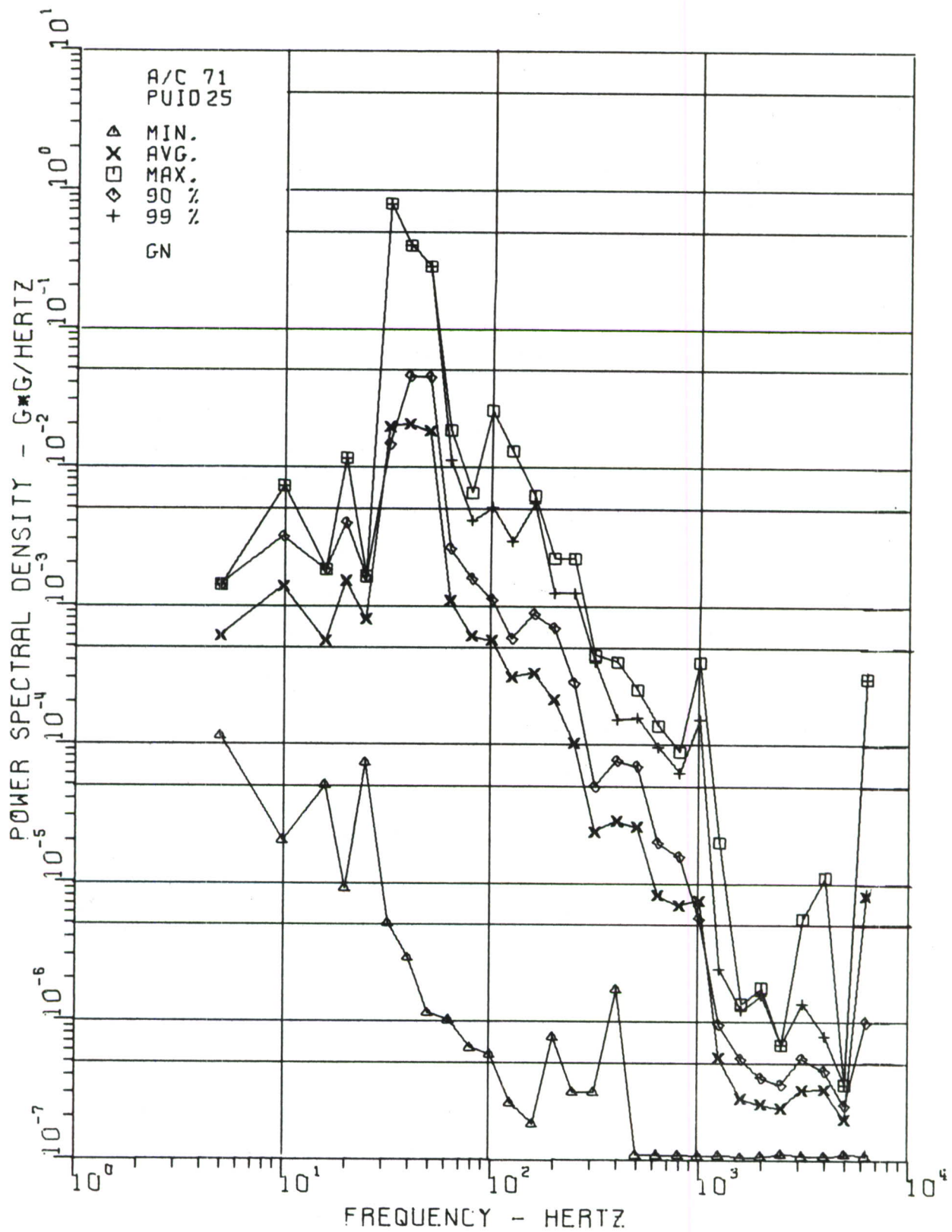


Figure 126. Pilot's Instrument Panel, Right Side, Sta. 115

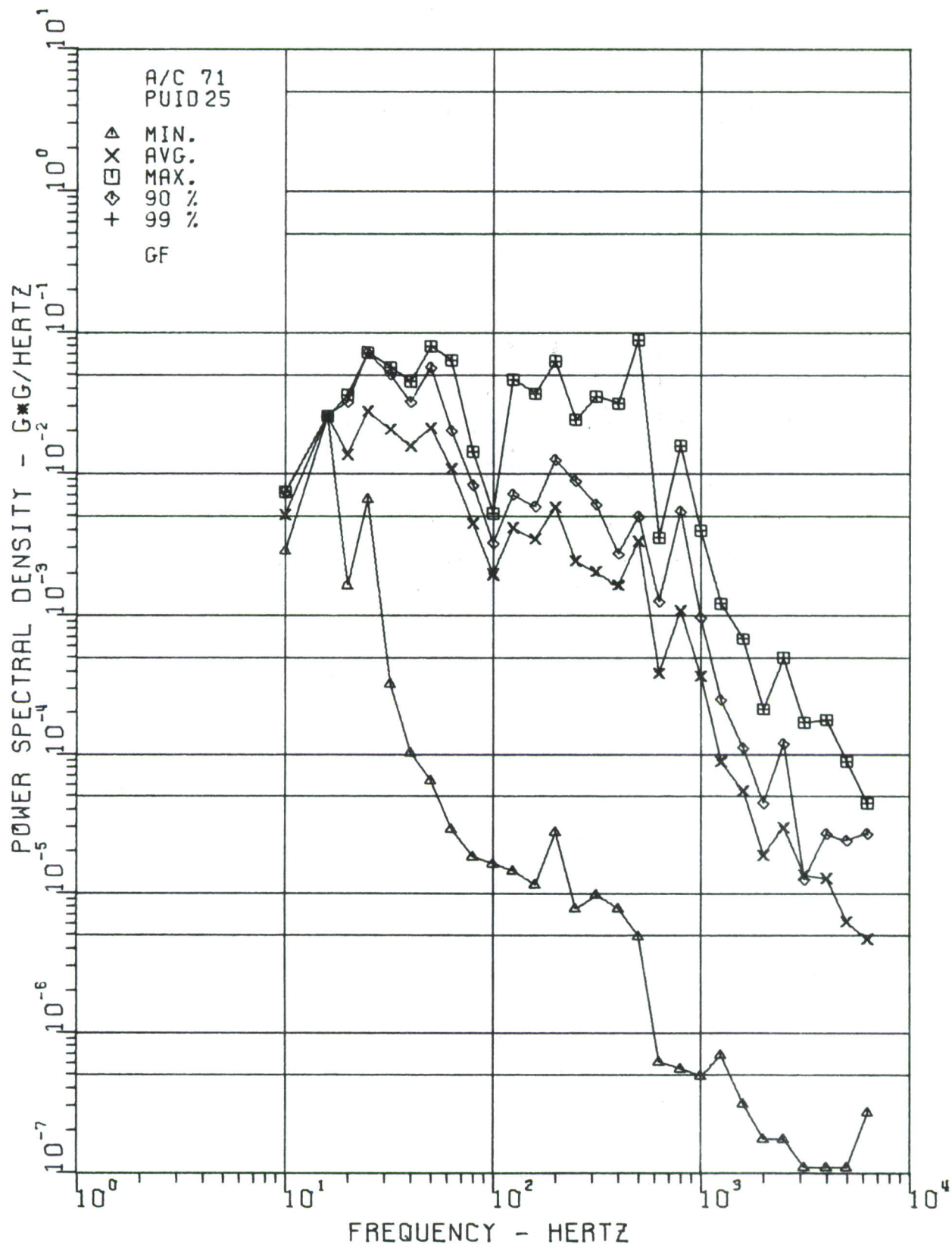


Figure 127. Pilot's Instrument Panel, Right Side, Sta. 115, with Gunfire

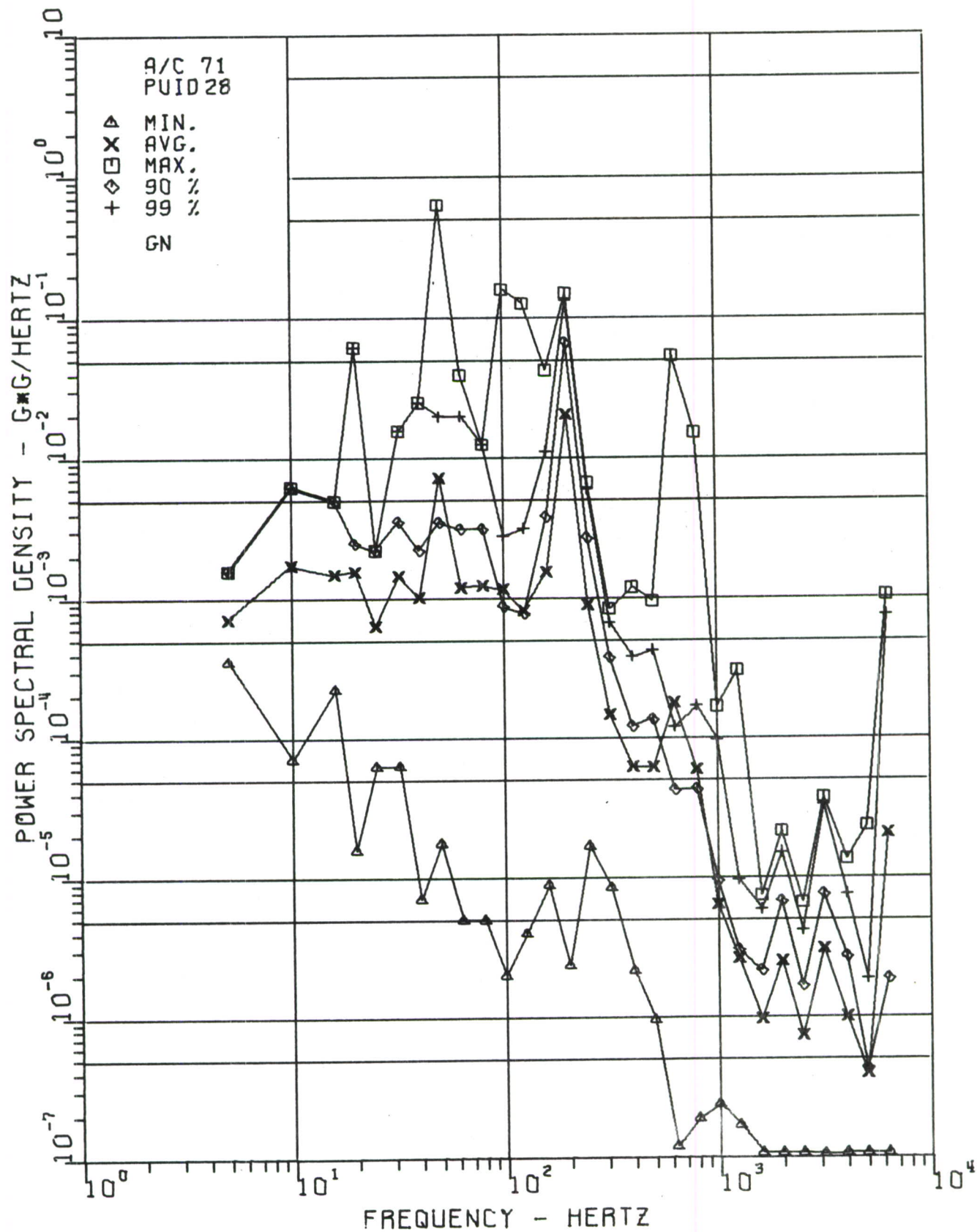


Figure 128. Pilot's Pedestal, Left Side, Sta. 122

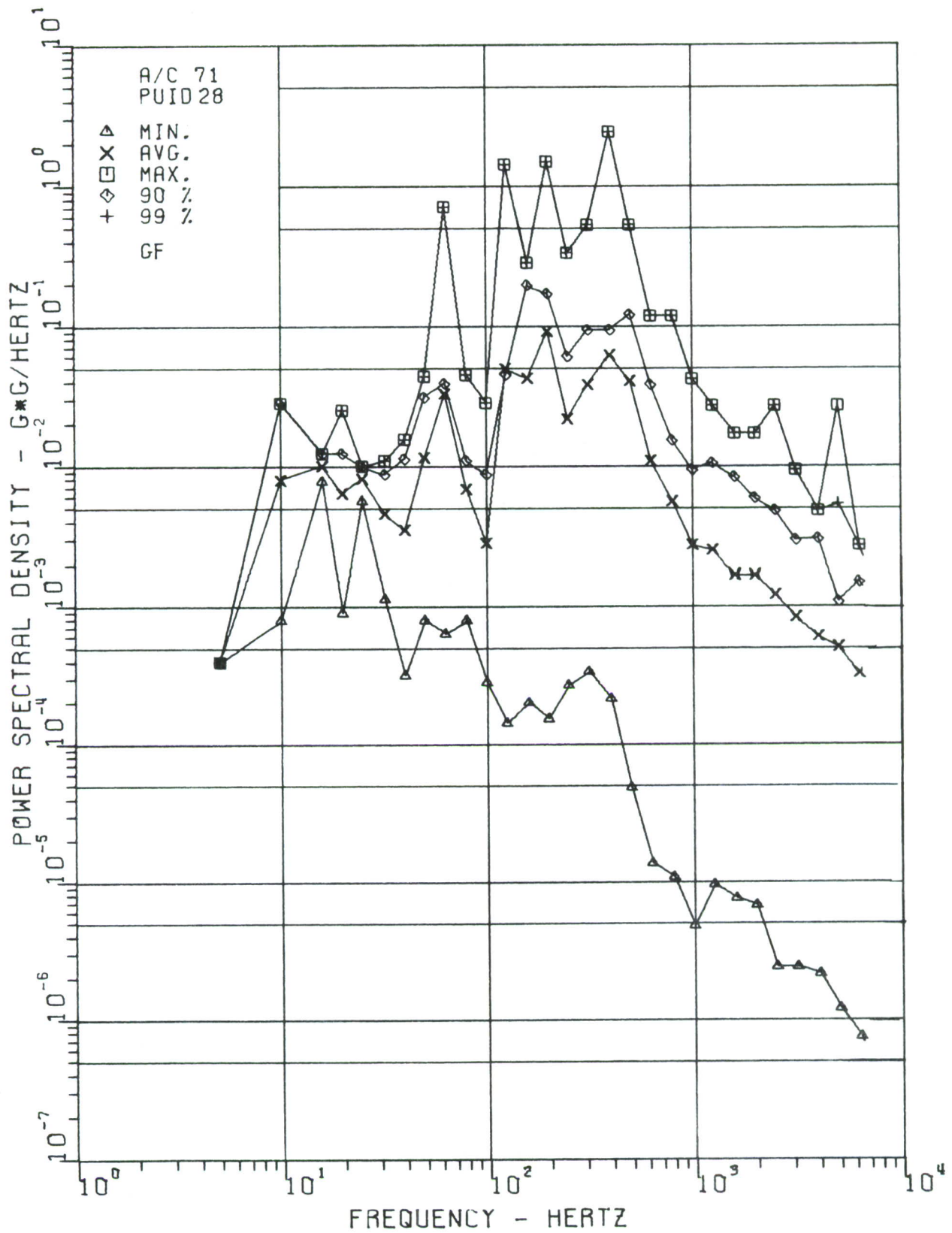


Figure 129. Pilot's Pedestal, Left Side, Sta. 122, with Gunfire

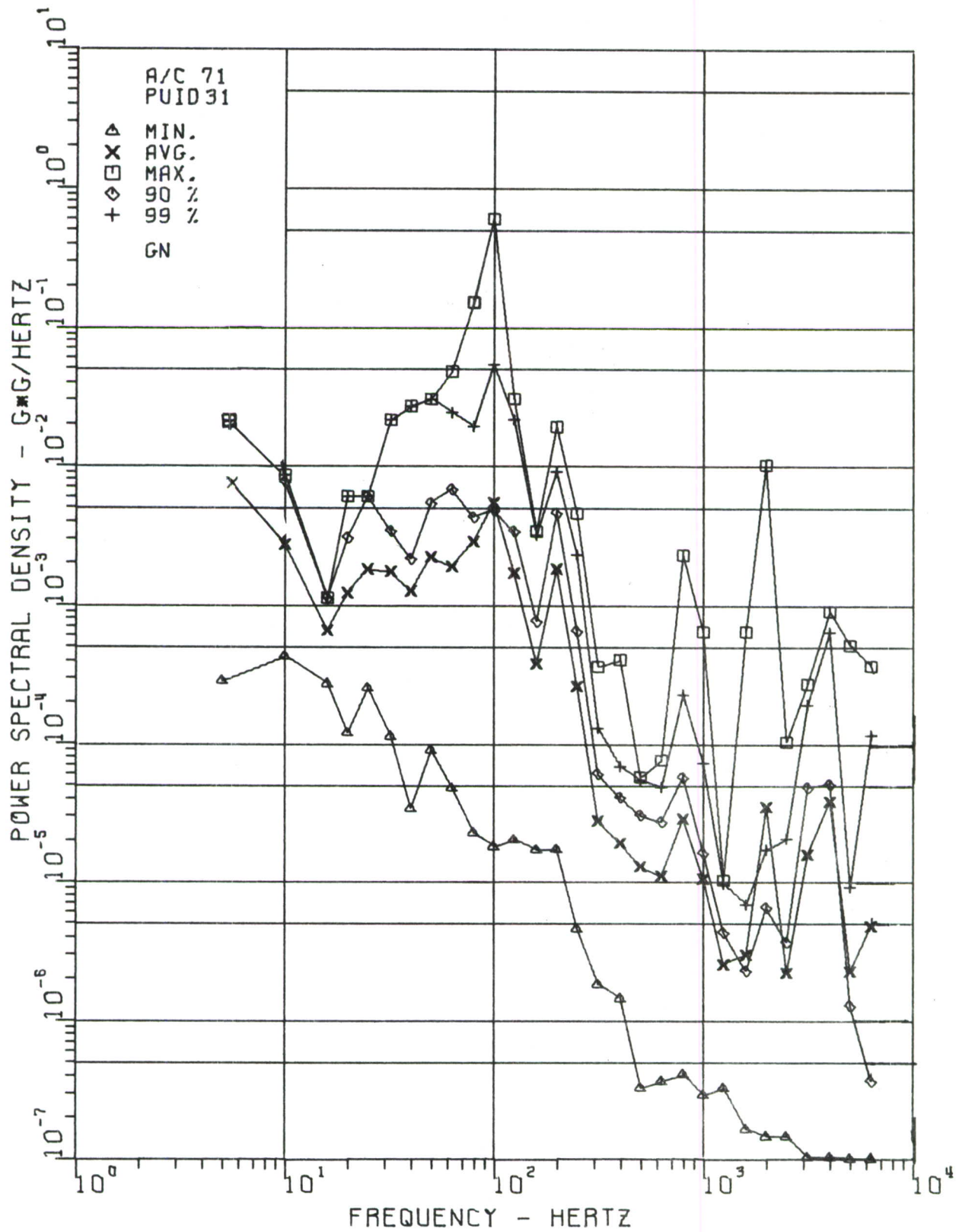


Figure 130. Pilot's Instrument Comp., Left Side, Sta. 122

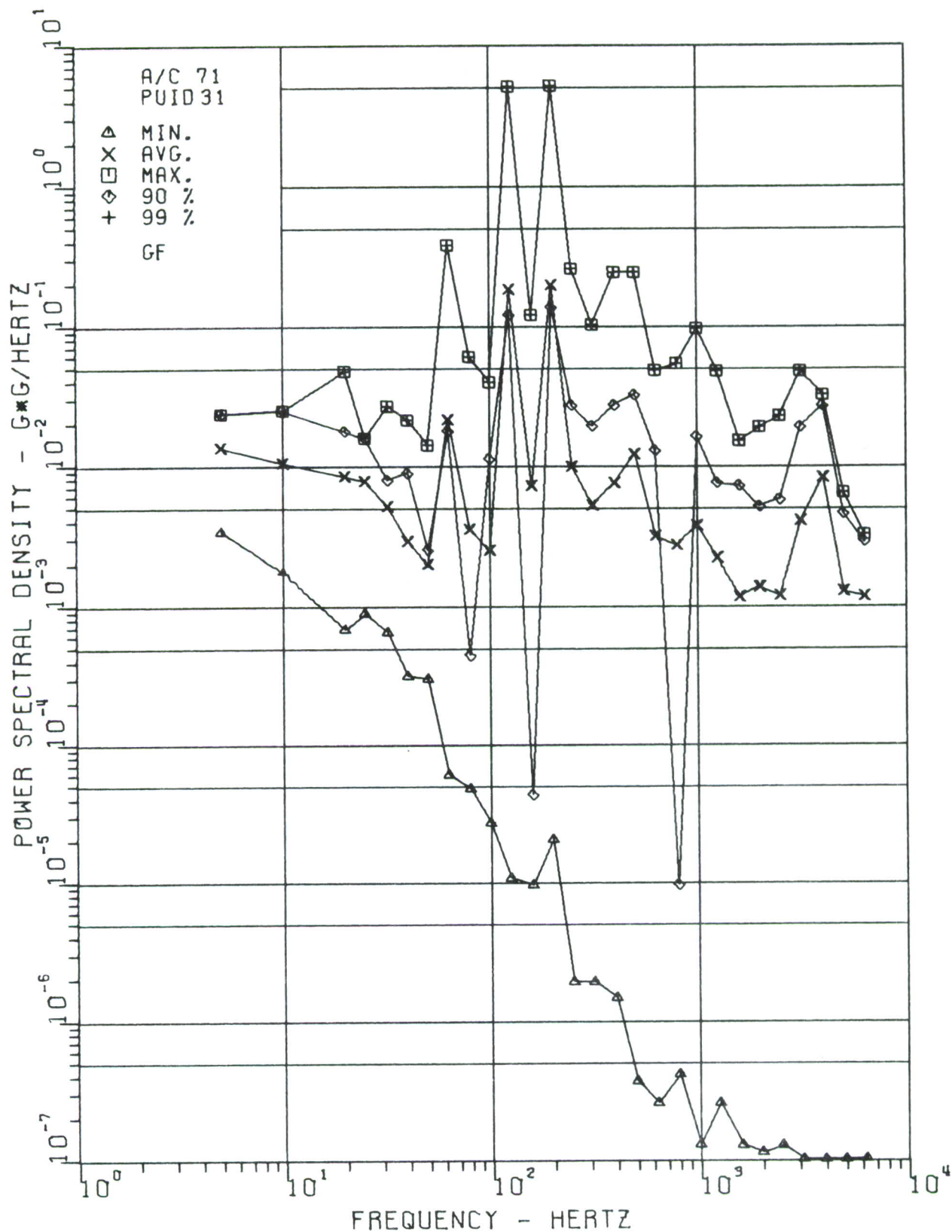


Figure 131. Pilot's Instrument Comp., Left Side, Sta. 122
with Gunfire

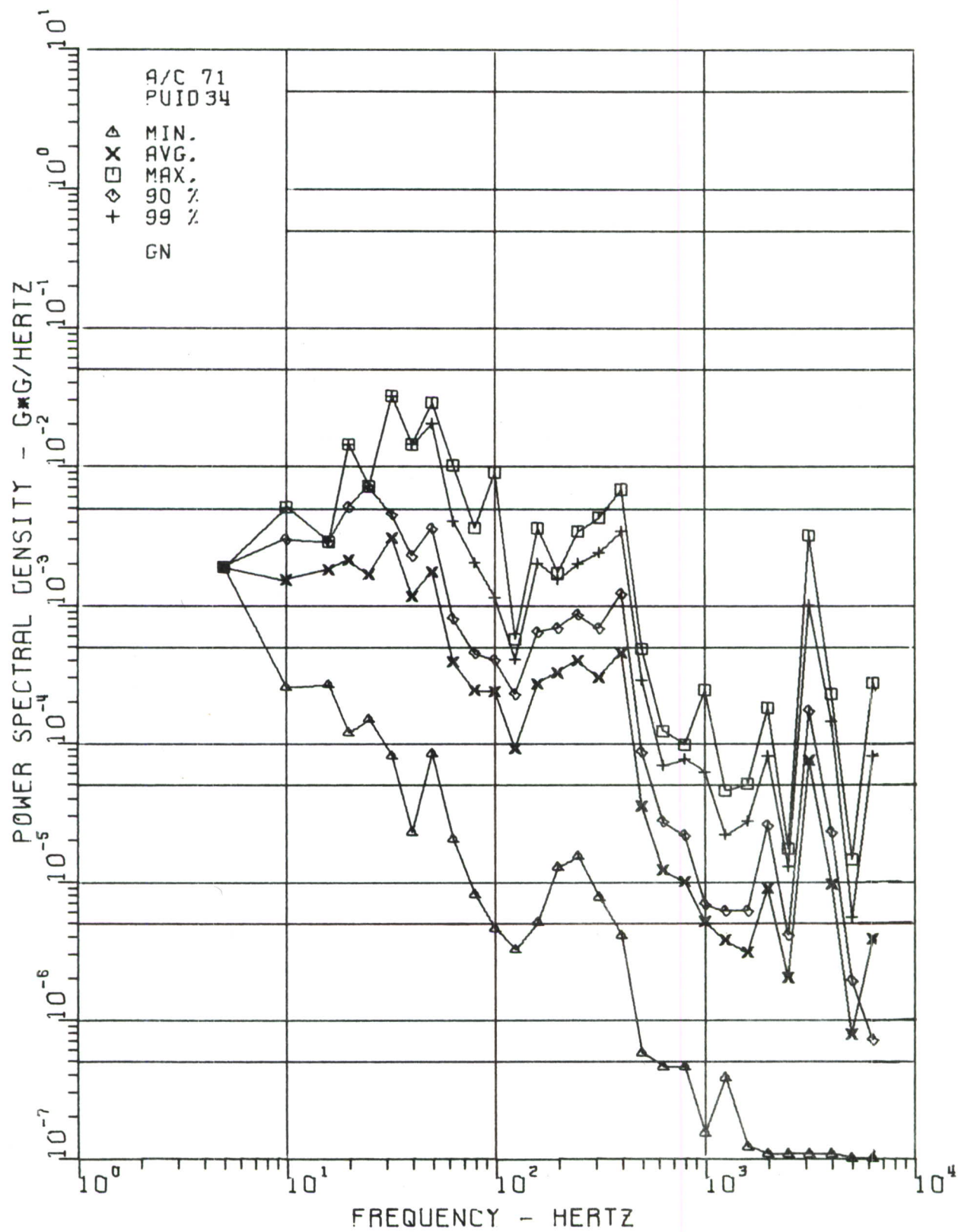


Figure 132. Pilot's Instrument Comp., Right Side, Sta. 130

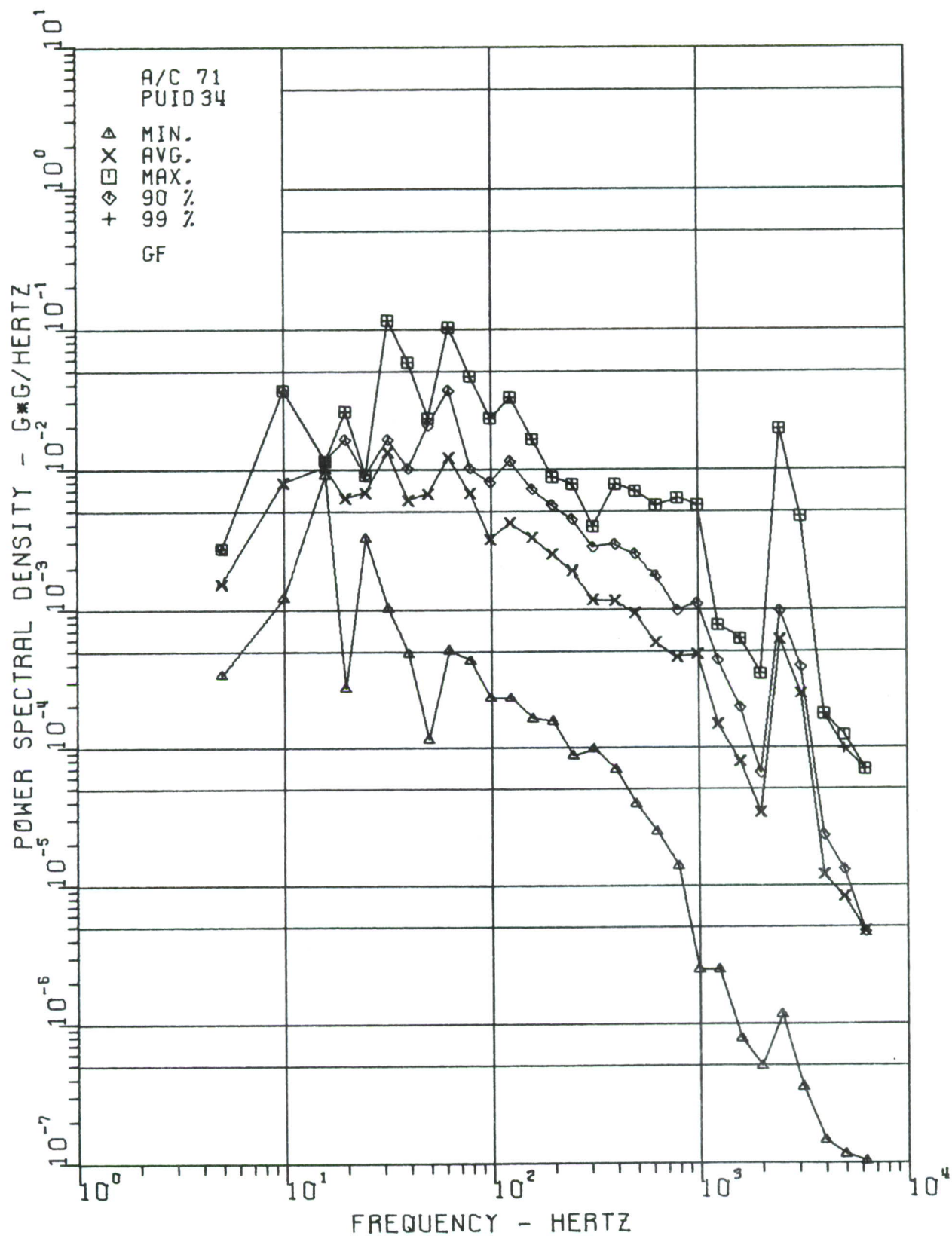


Figure 133. Pilot's Instrument Comp., Right Side, Sta. 130,
with Gunfire

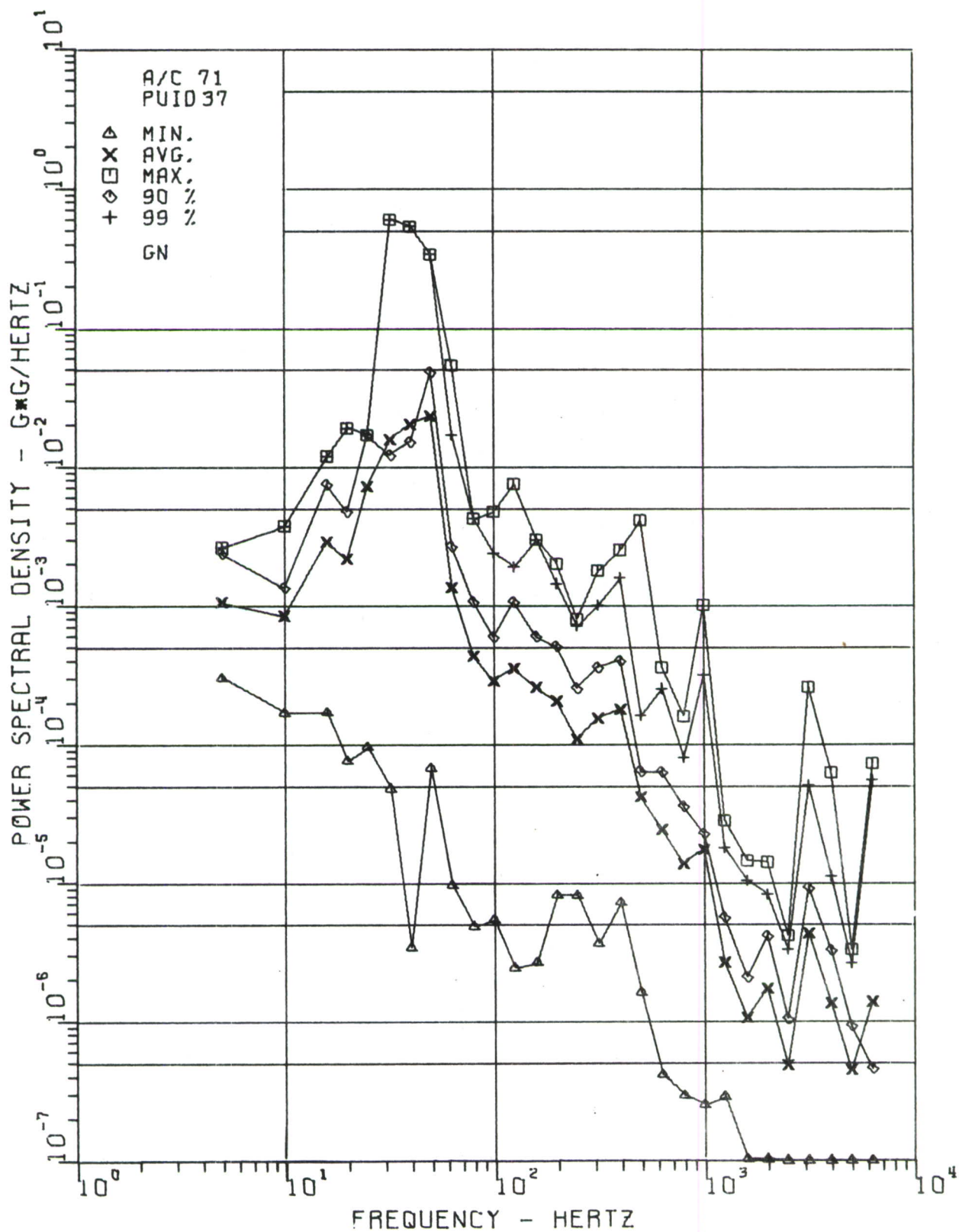


Figure 134. Pilot's Pedestal, Right Side, Sta. 136

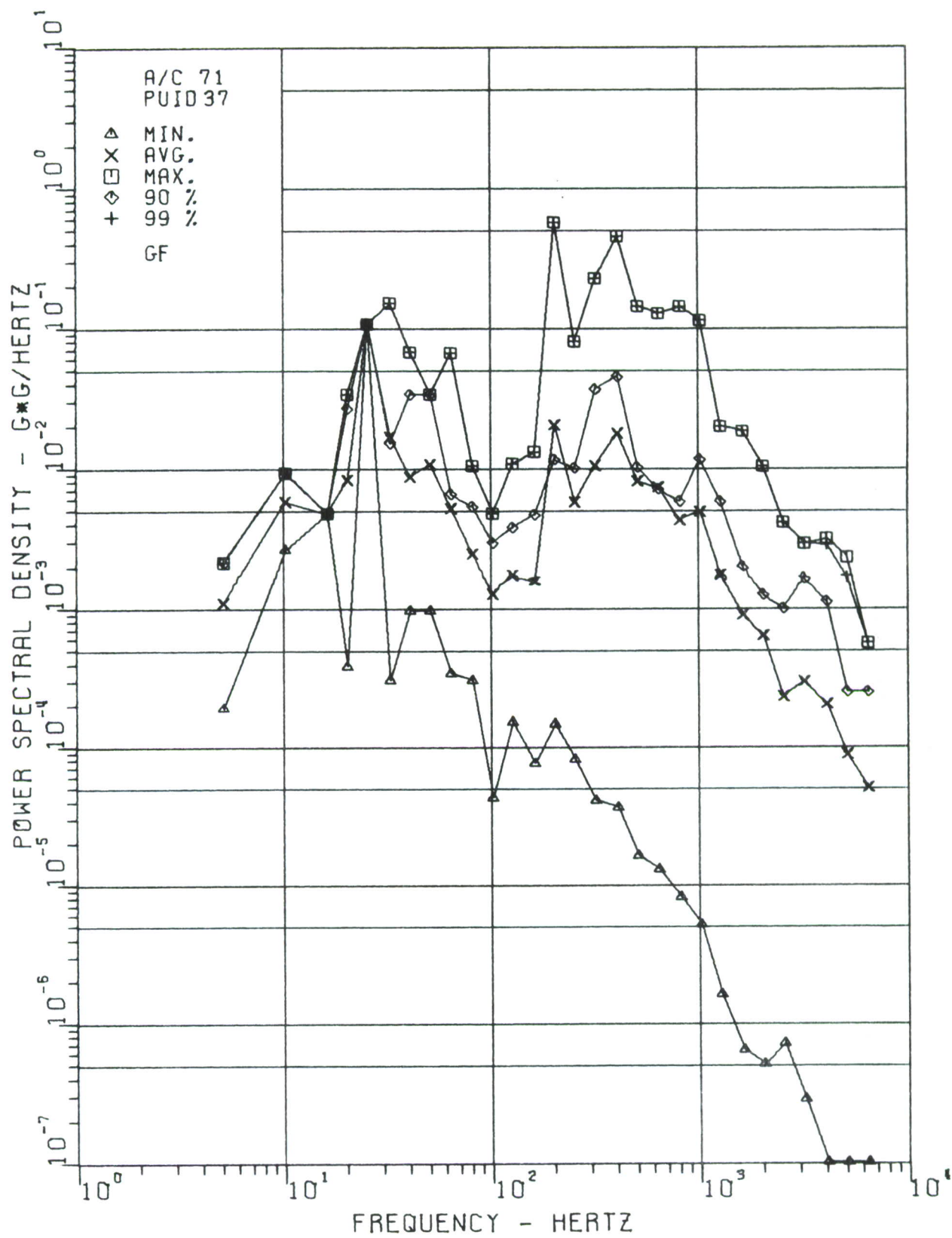


Figure 135. Pilot's Pedestal, Right Side, Sta. 136, with Gunfire

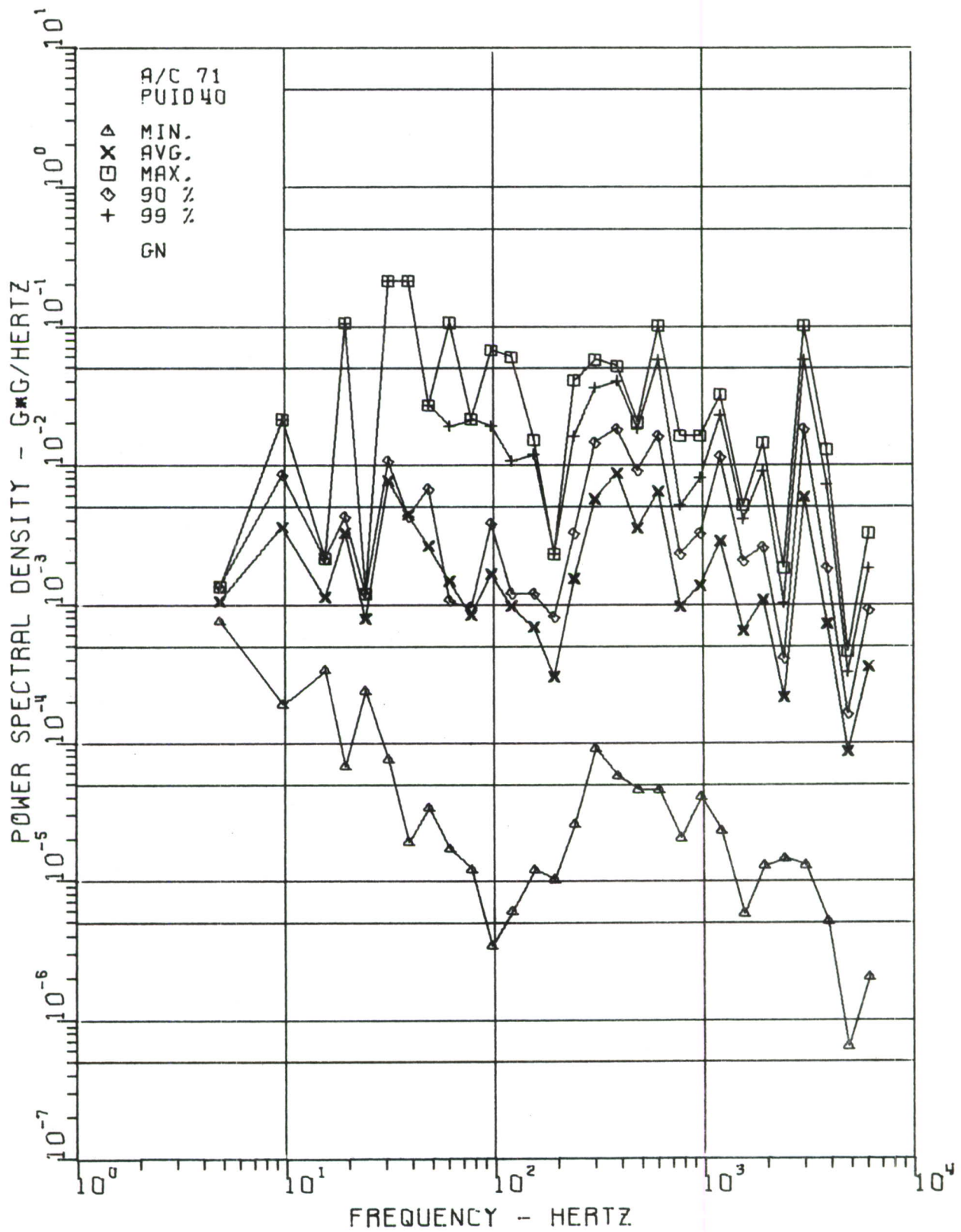


Figure 136. Main Transmission Mount, Left Front, Sta. 188

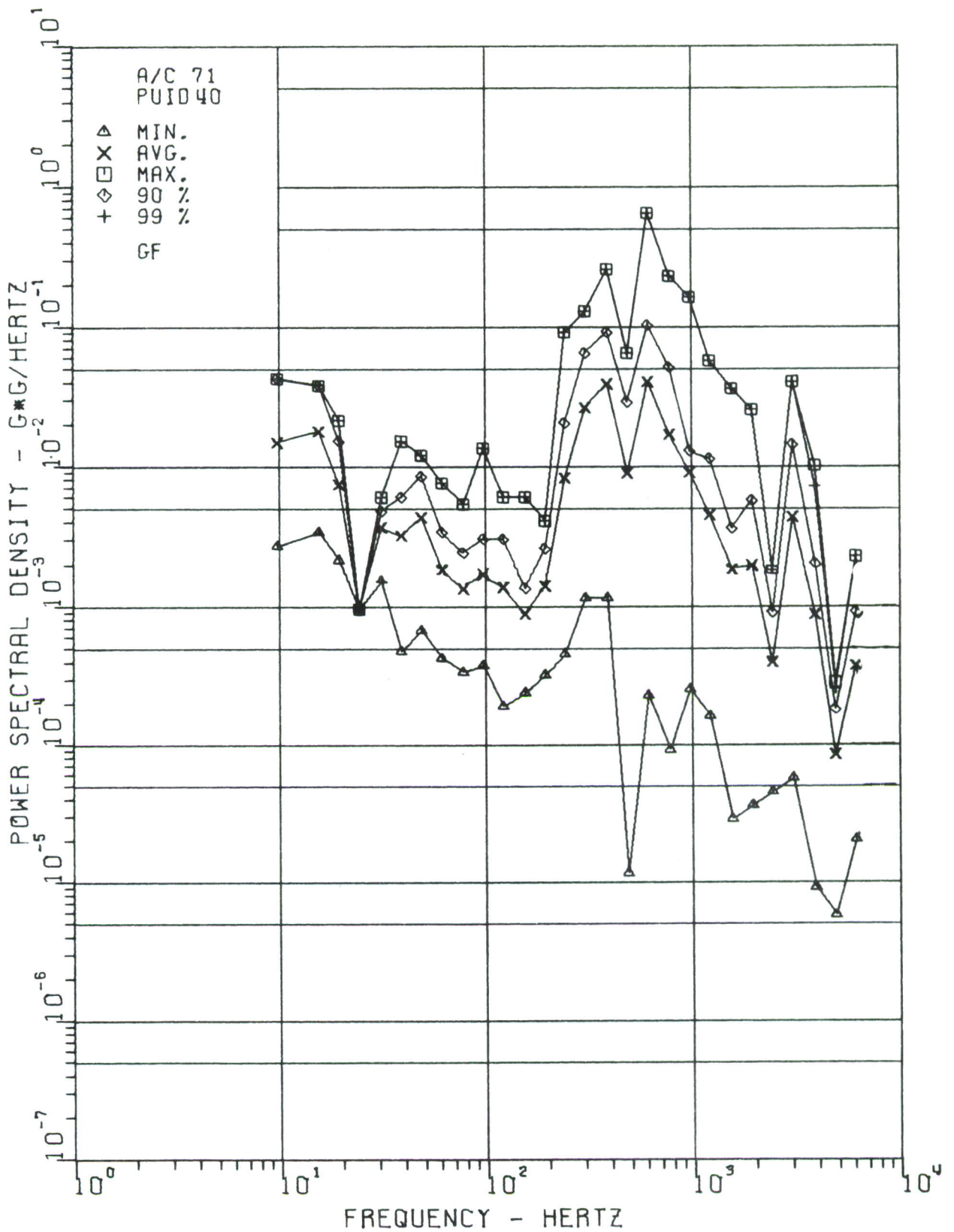


Figure 137. Main Transmission Mount, Left Front, Sta. 188
with Gunfire

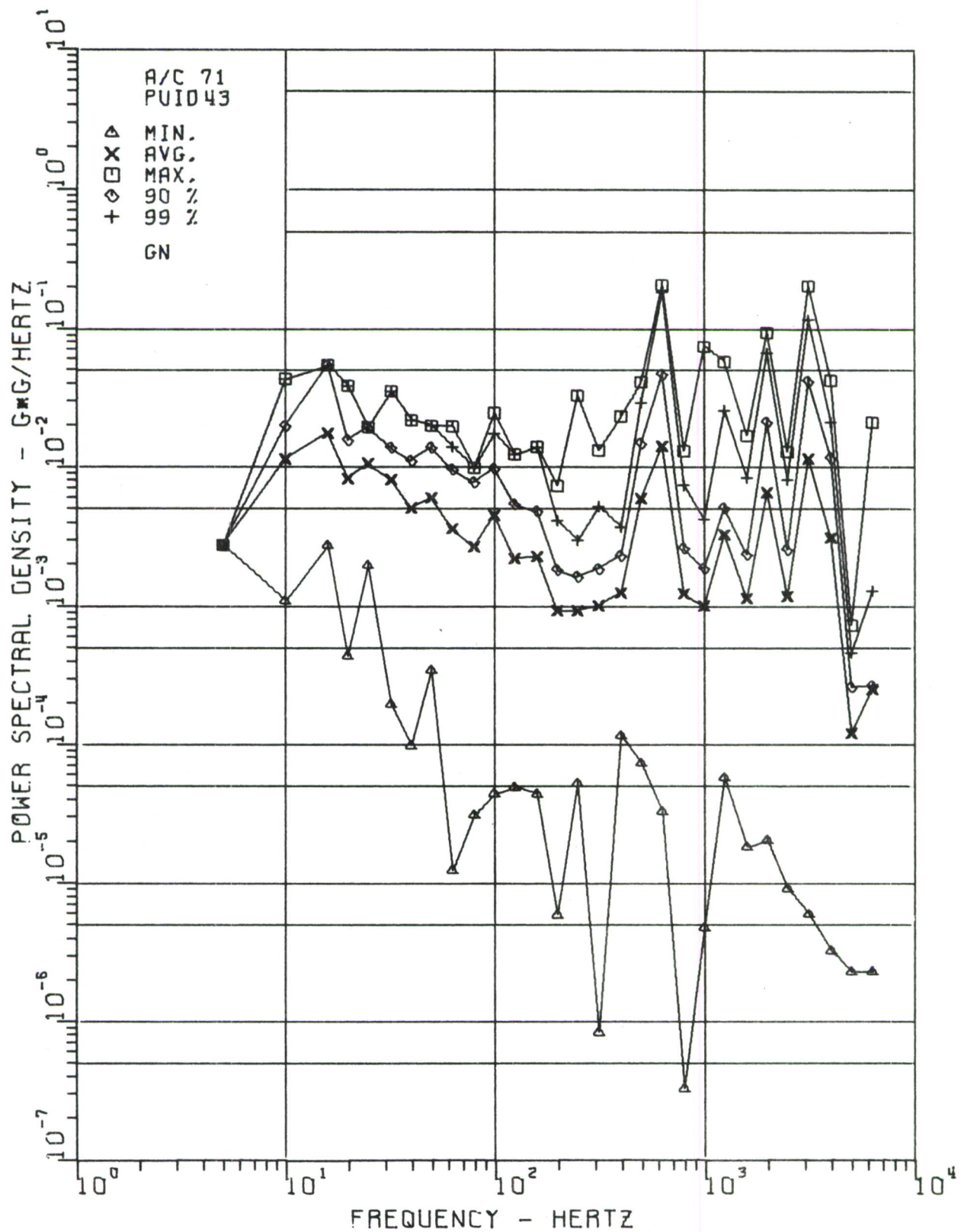


Figure 138. Main Transmission Mount, Right Rear, Sta. 202

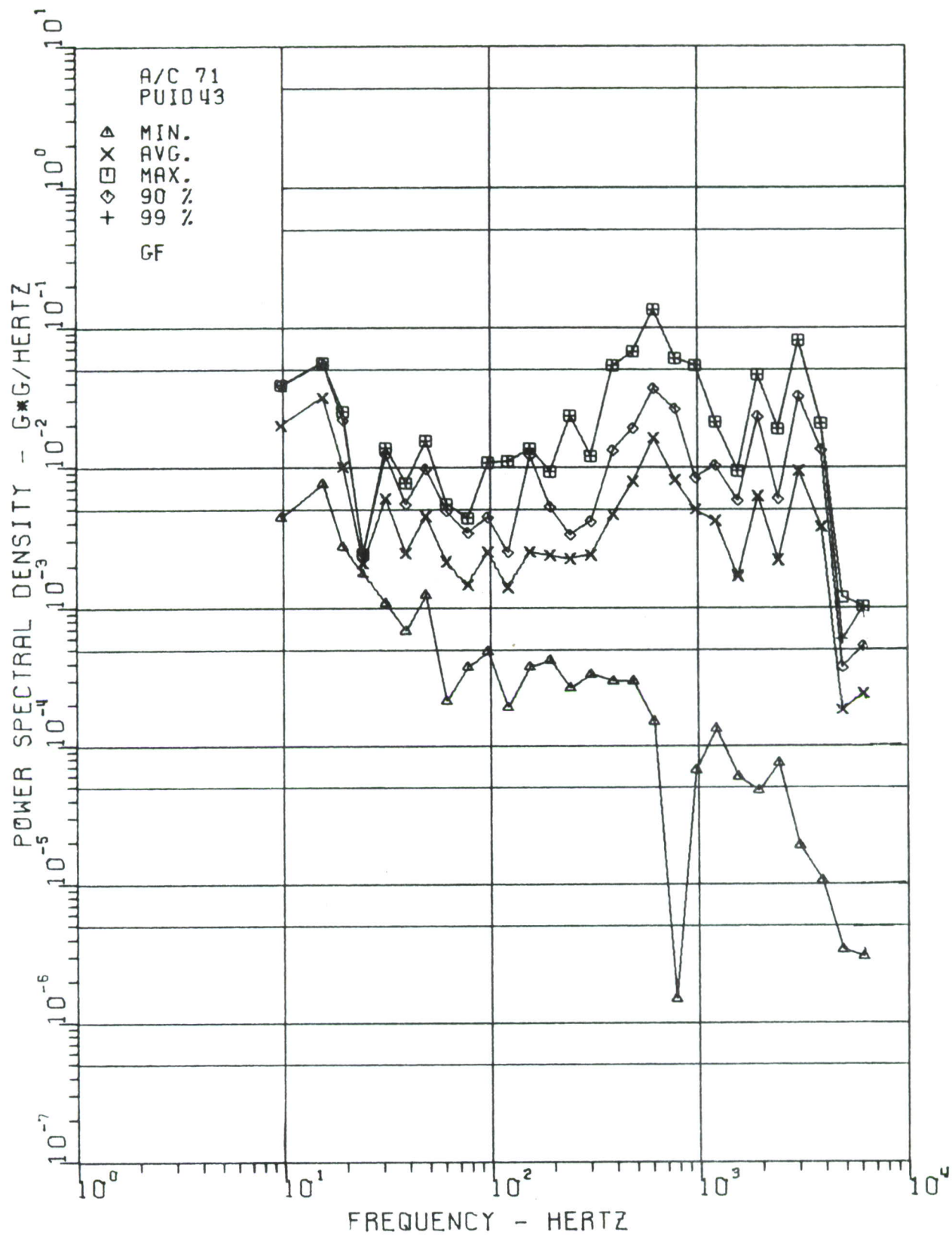


Figure 139. Main Transmission Mount, Right Rear, Sta. 202, with Gunfire

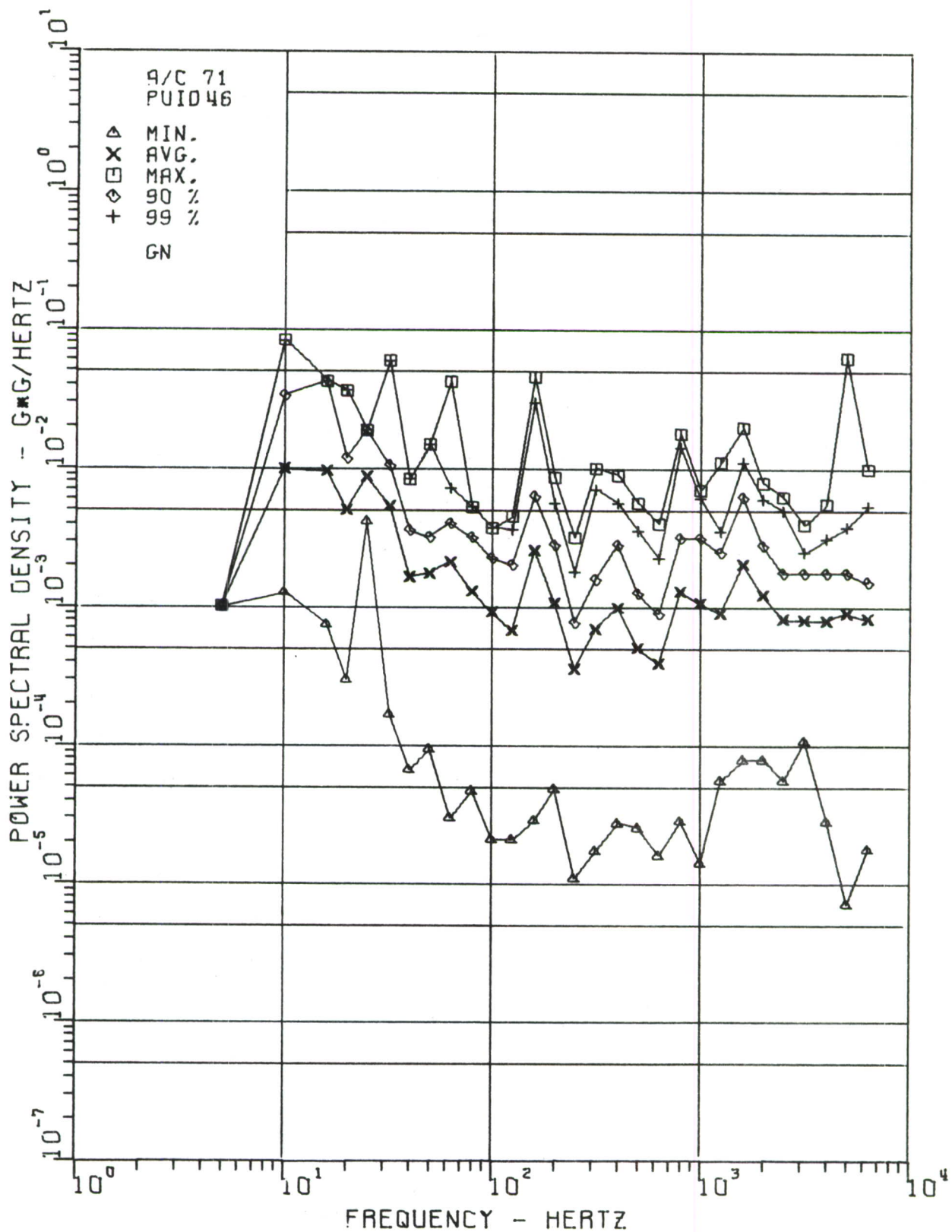


Figure 140. Engine Mount, Left Side, Sta. 244

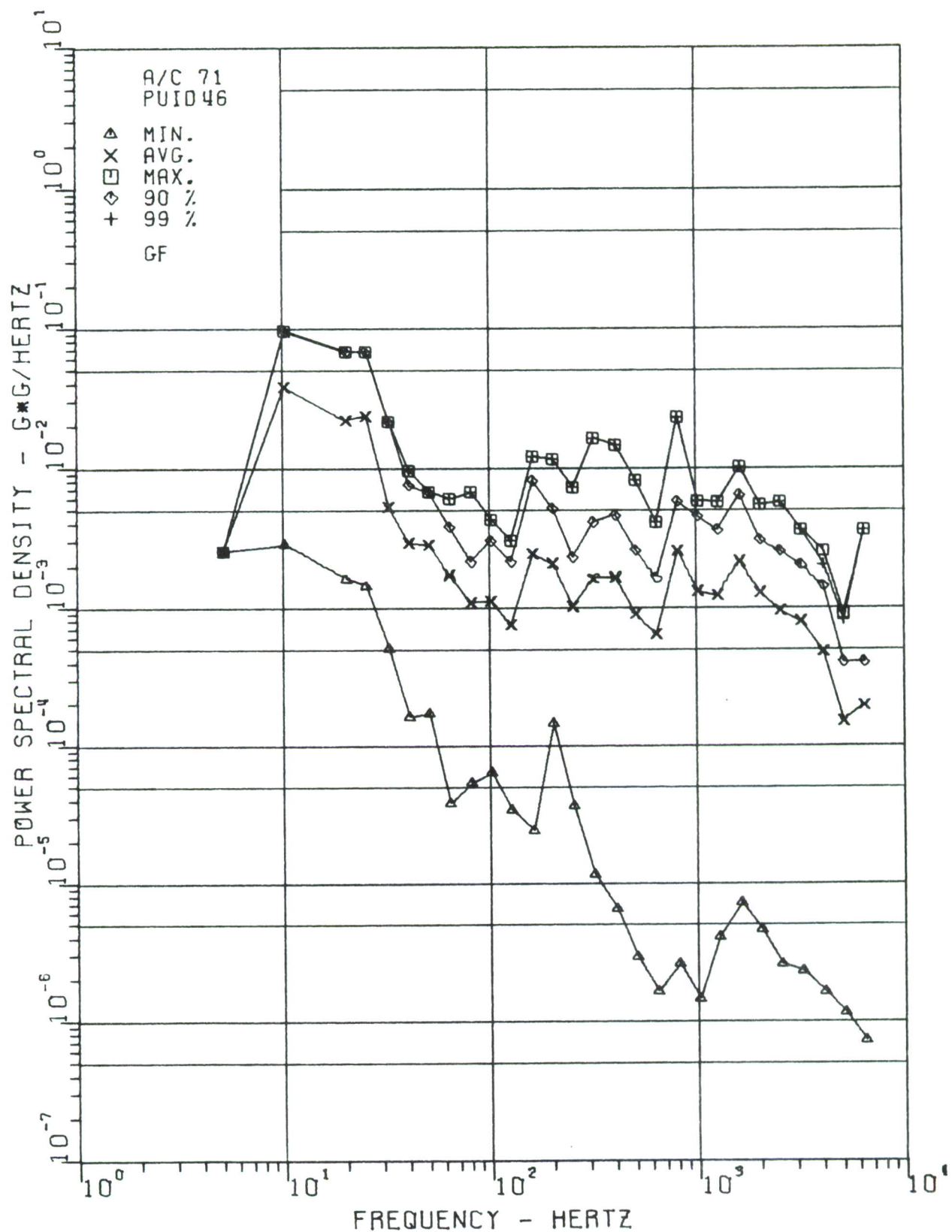


Figure 141. Engine Mount, Left Side, Sta. 244, with Gunfire

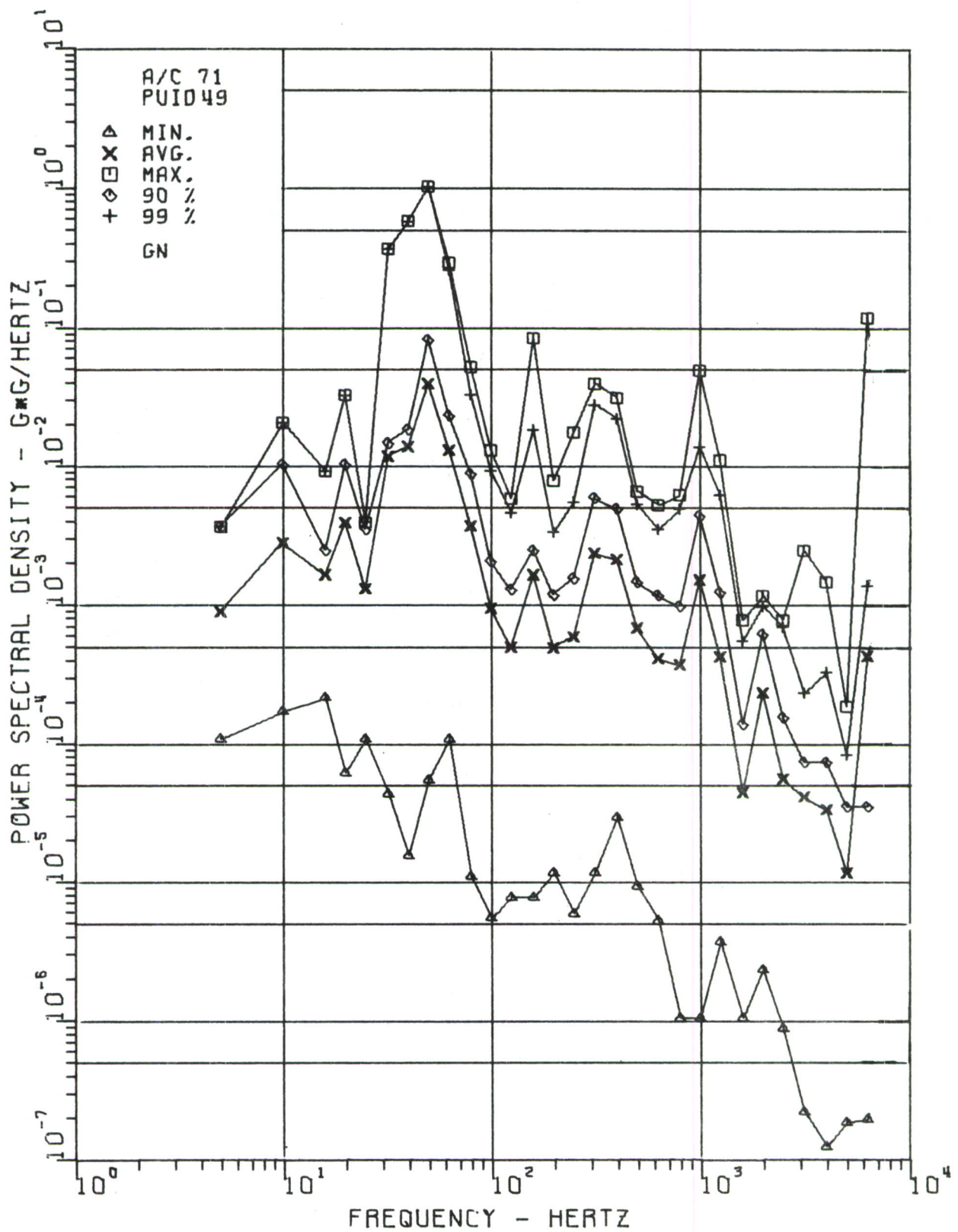


Figure 142. Right Wing, Top Outboard, Sta. 191

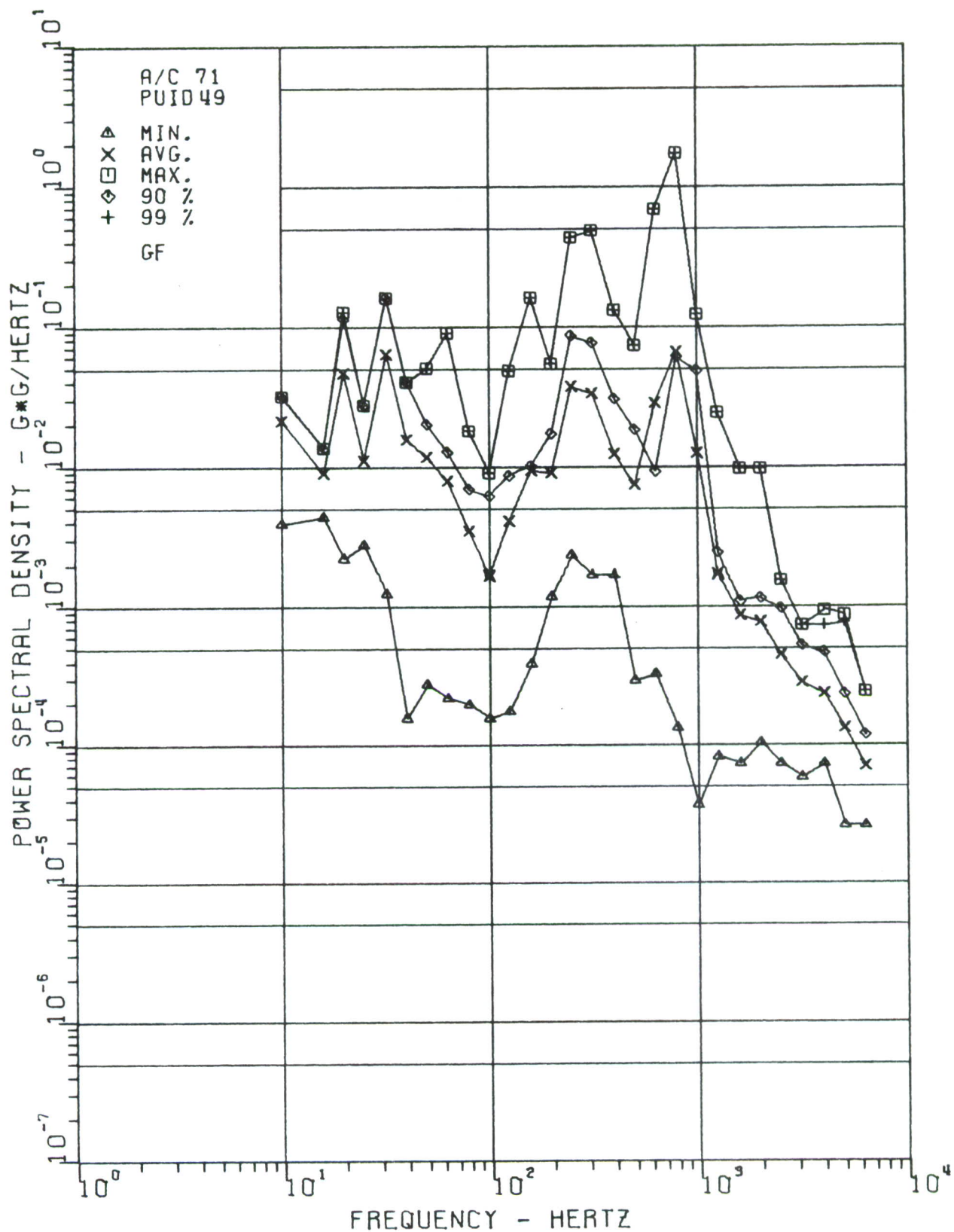


Figure 143. Right Wing, Top Outboard, Sta. 191, with Gunfire

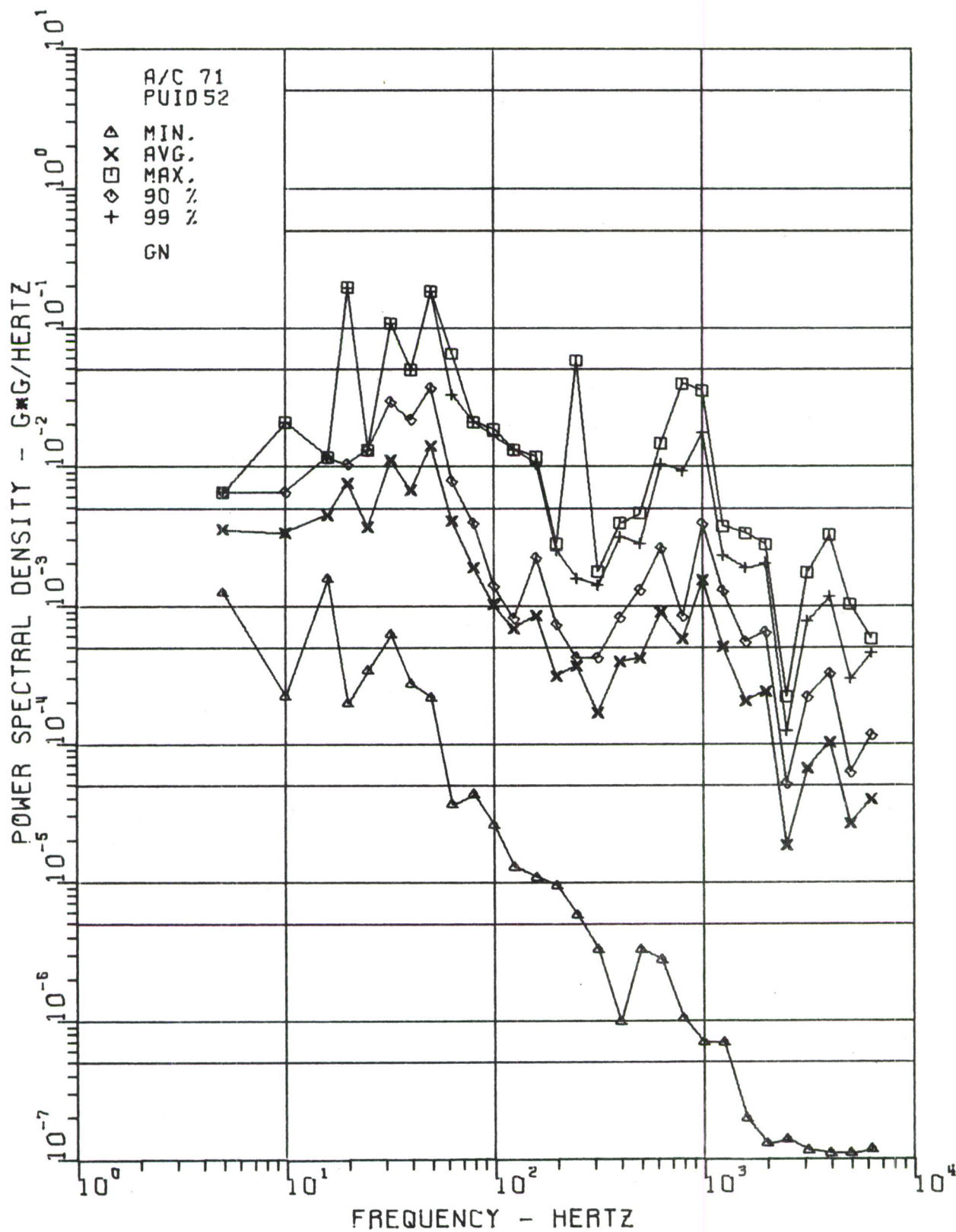


Figure 144. Right Wing, Top Inboard, Sta. 186

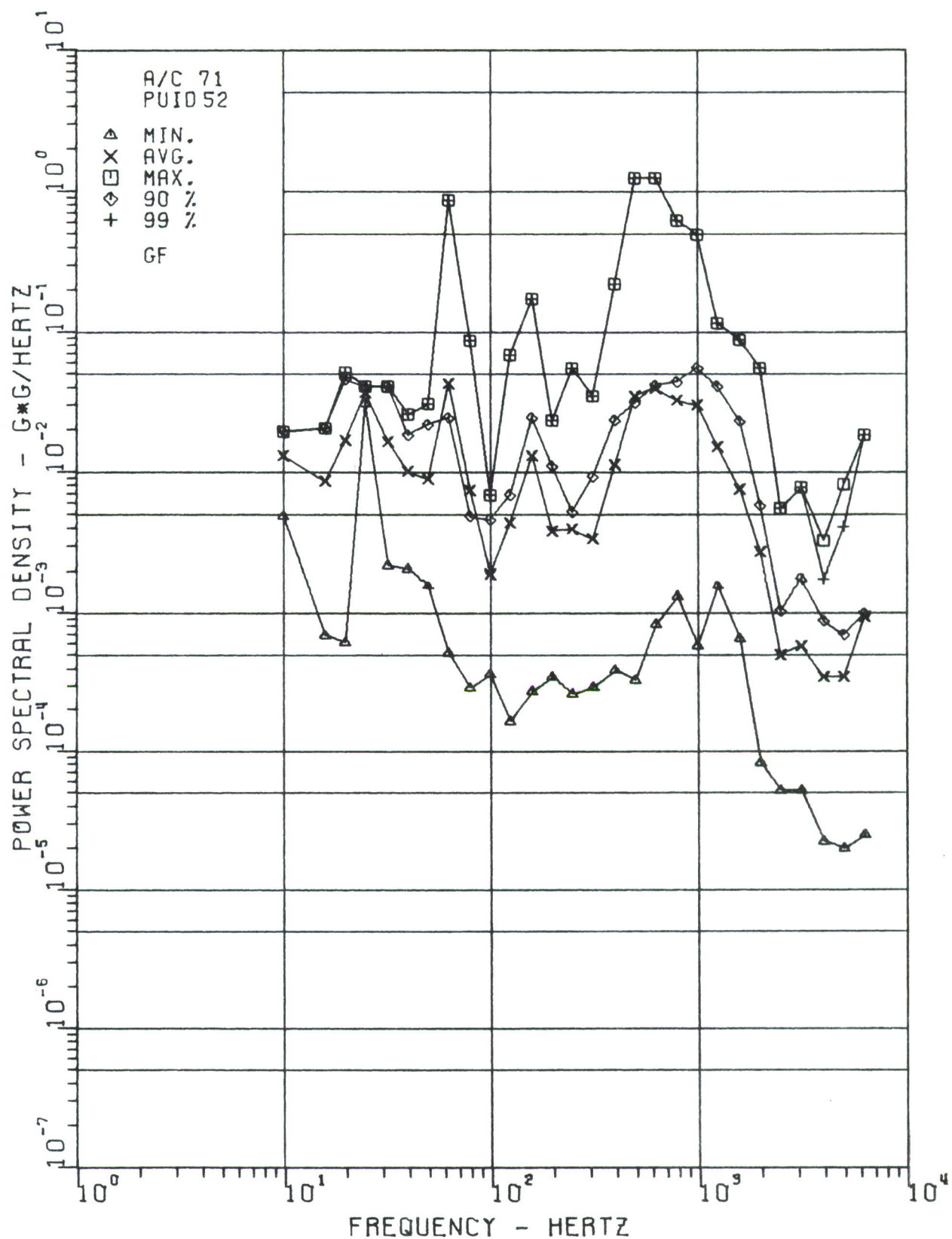


Figure 145. Right Wing, Top Inboard, Sta. 186, with Gunfire

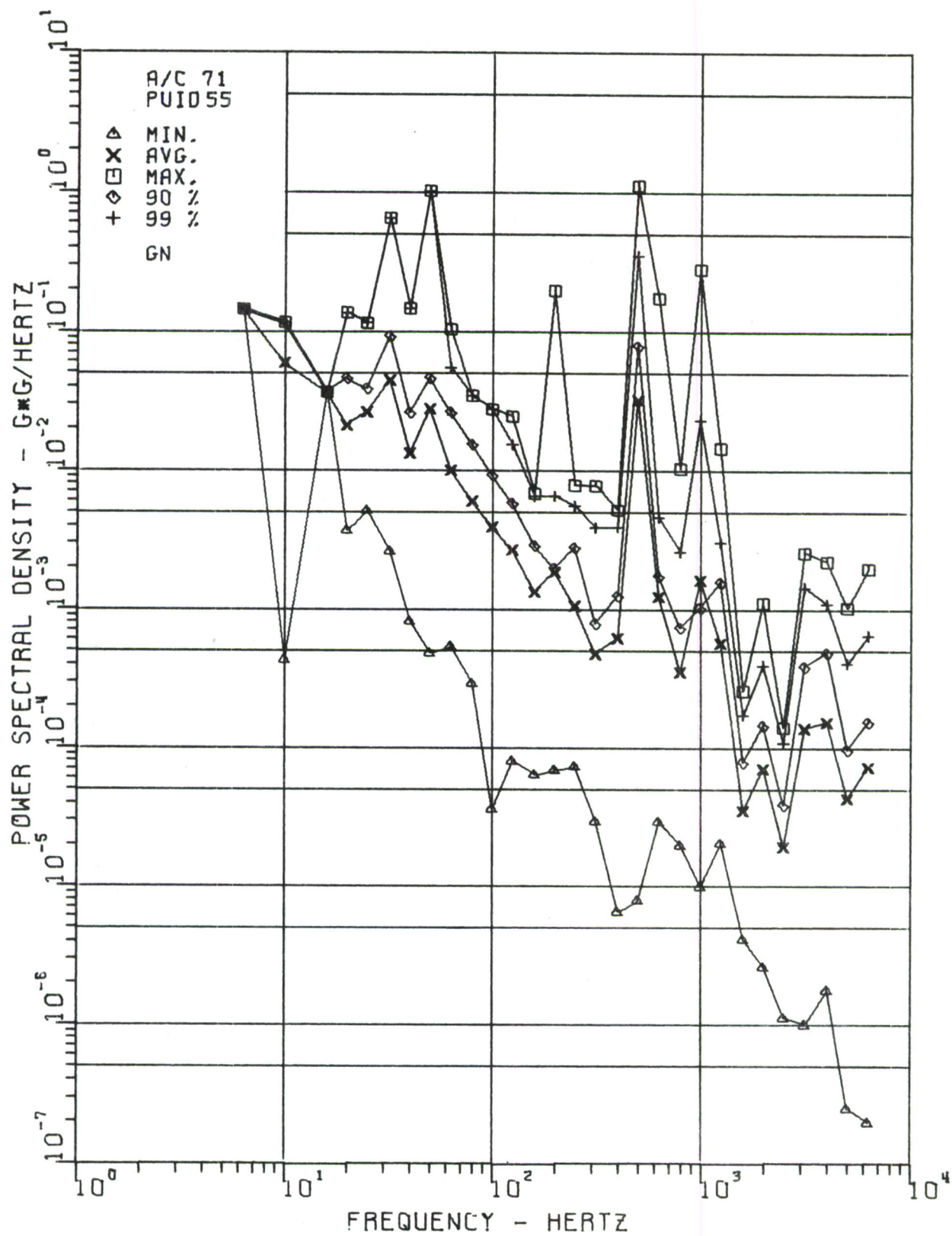


Figure 146. UHF-VHF Antenna Comp., Sta. 179

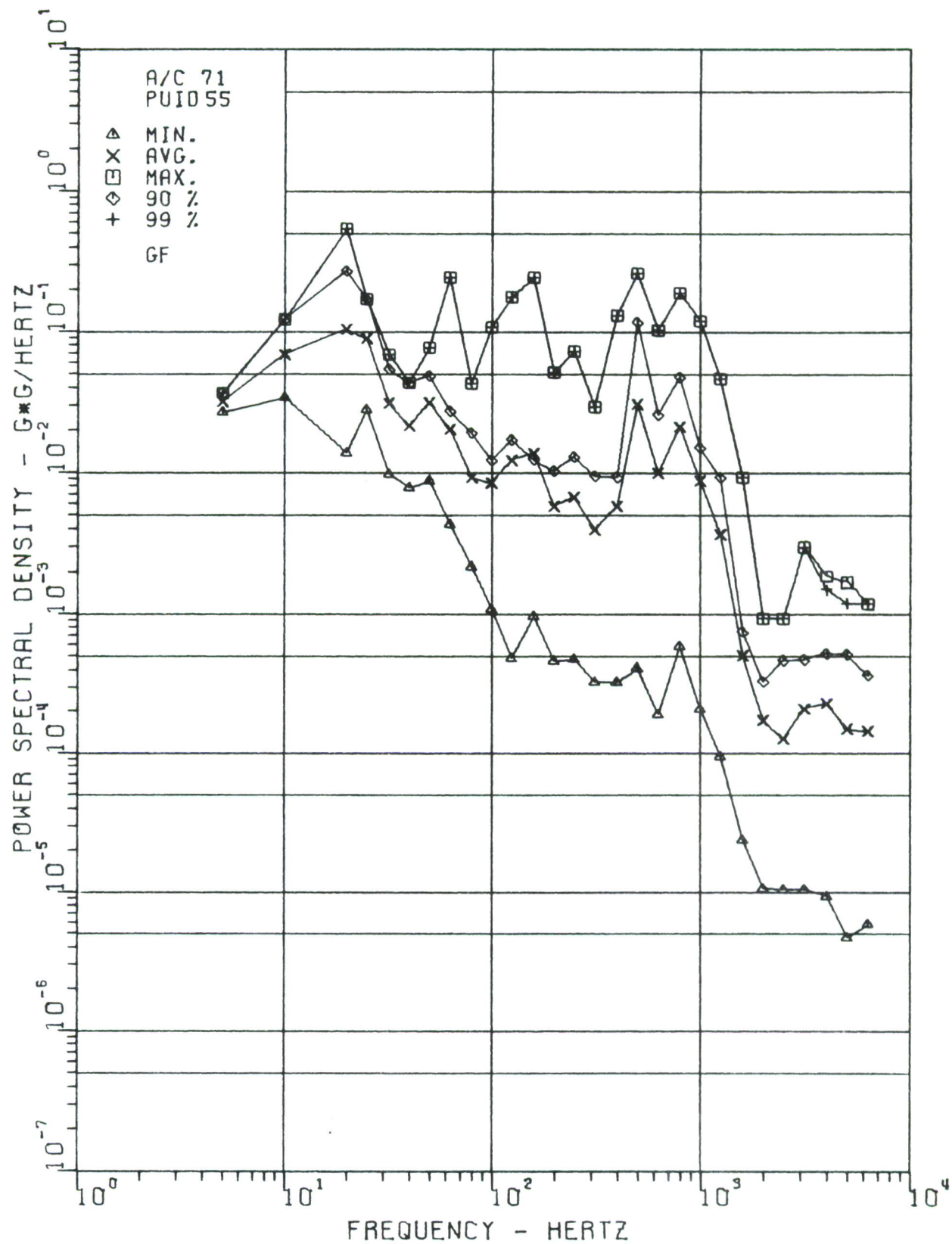


Figure 147. UHF-VHF Antenna Comp., Sta. 179, with Gunfire

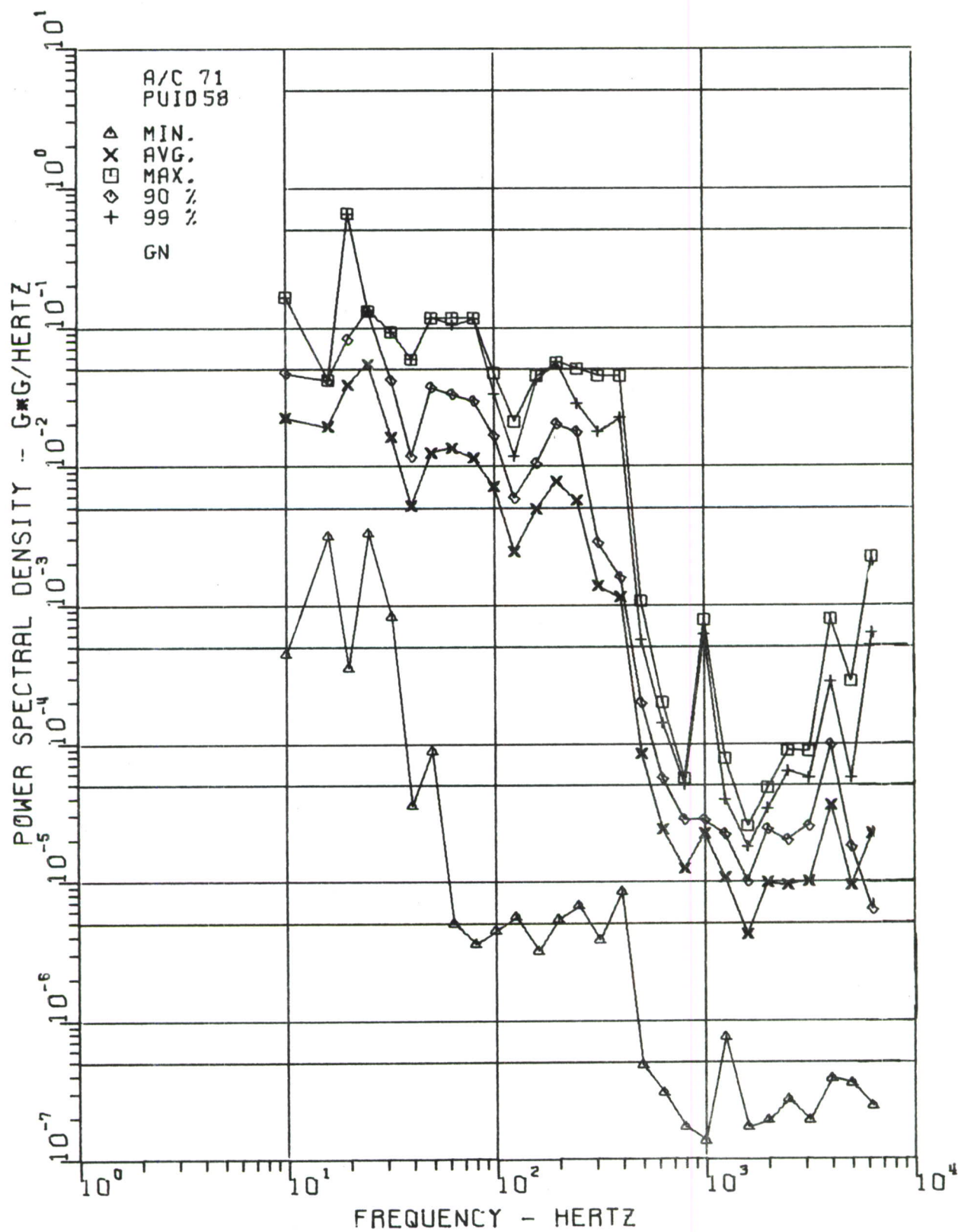


Figure 148. FM Antenna Comp., Sta 238

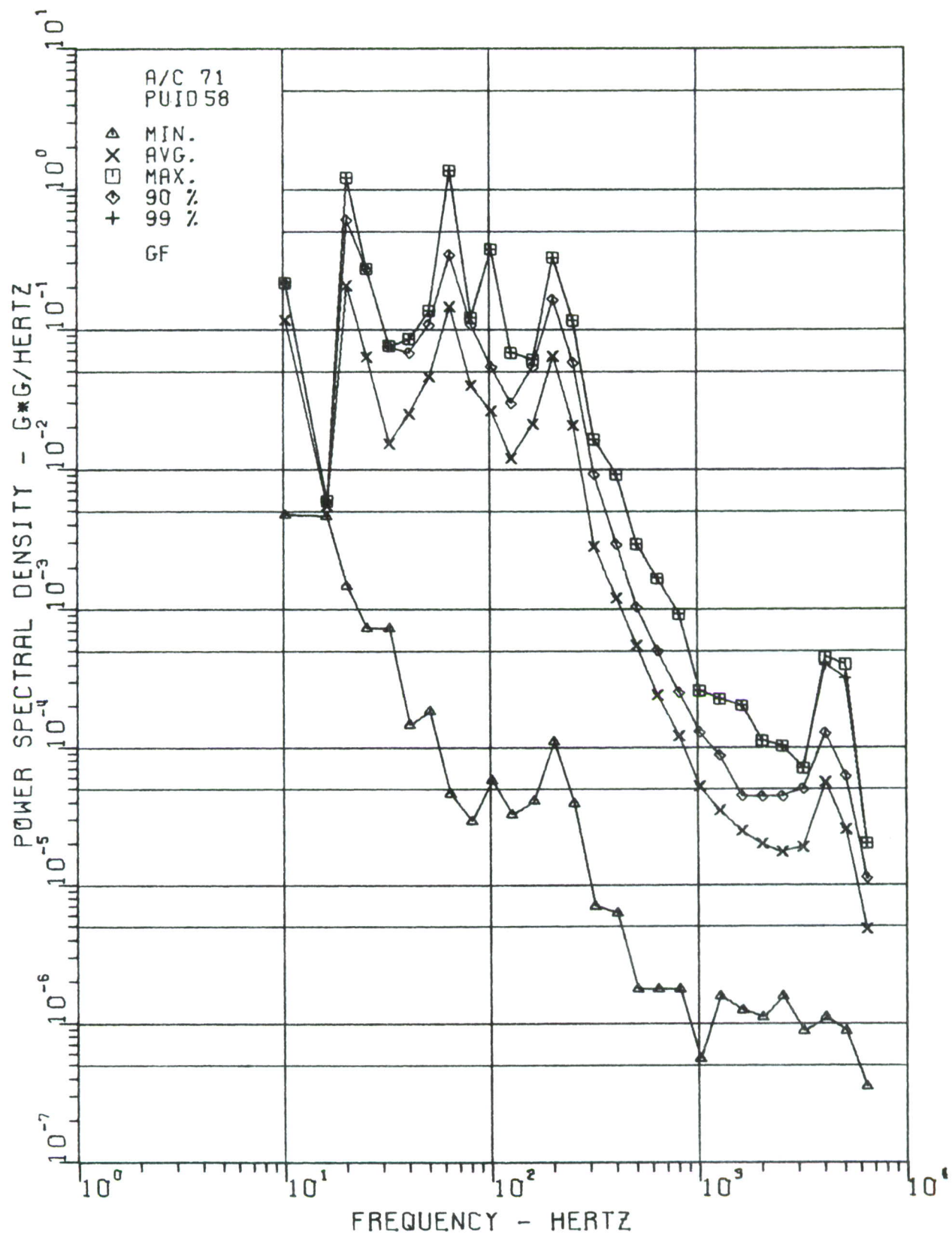


Figure 149. FM Antenna Comp., Sta. 238, with Gunfire

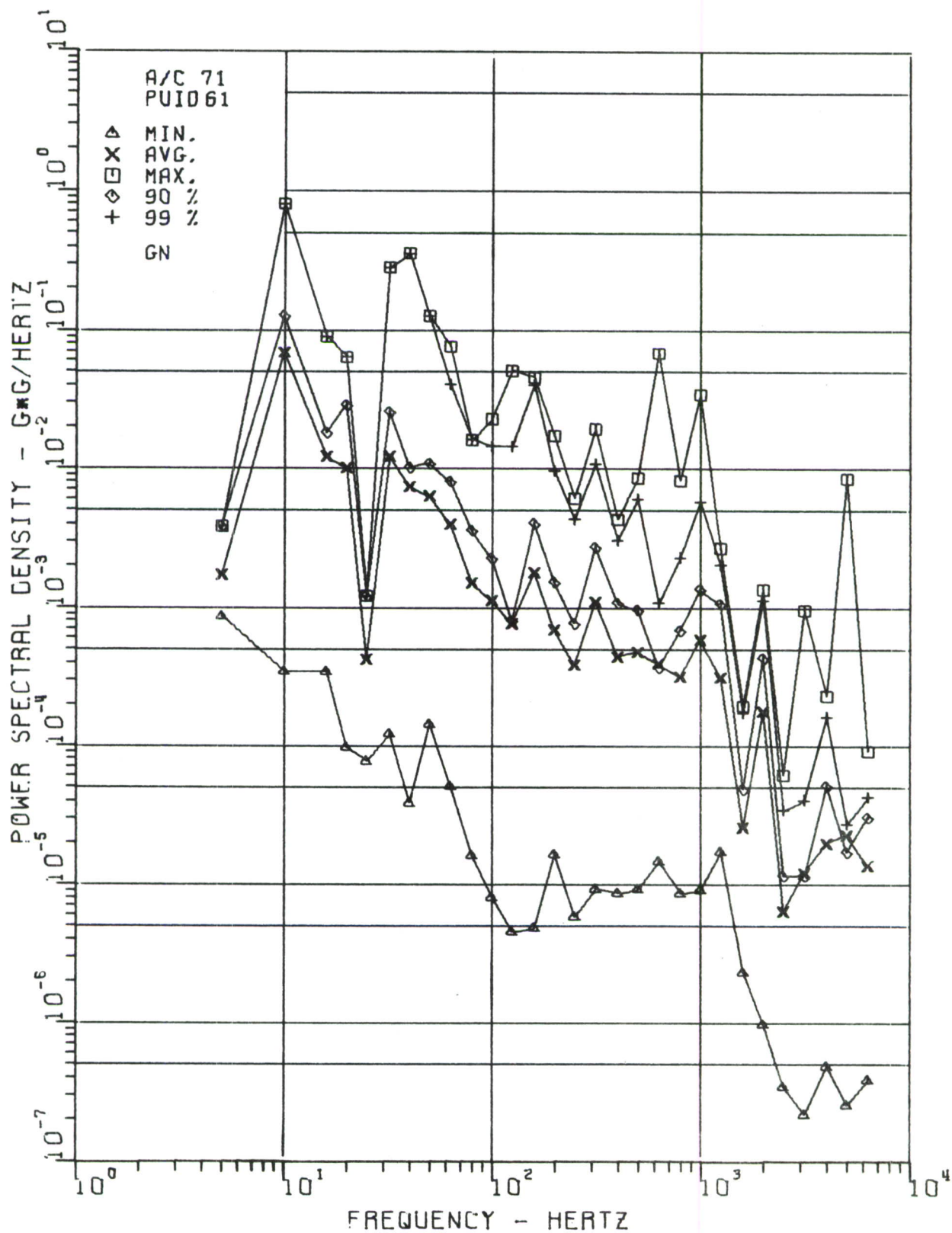


Figure 150. Aft Electrical Comp. near AN/ARN-83 Direction
Finder, Sta. 279

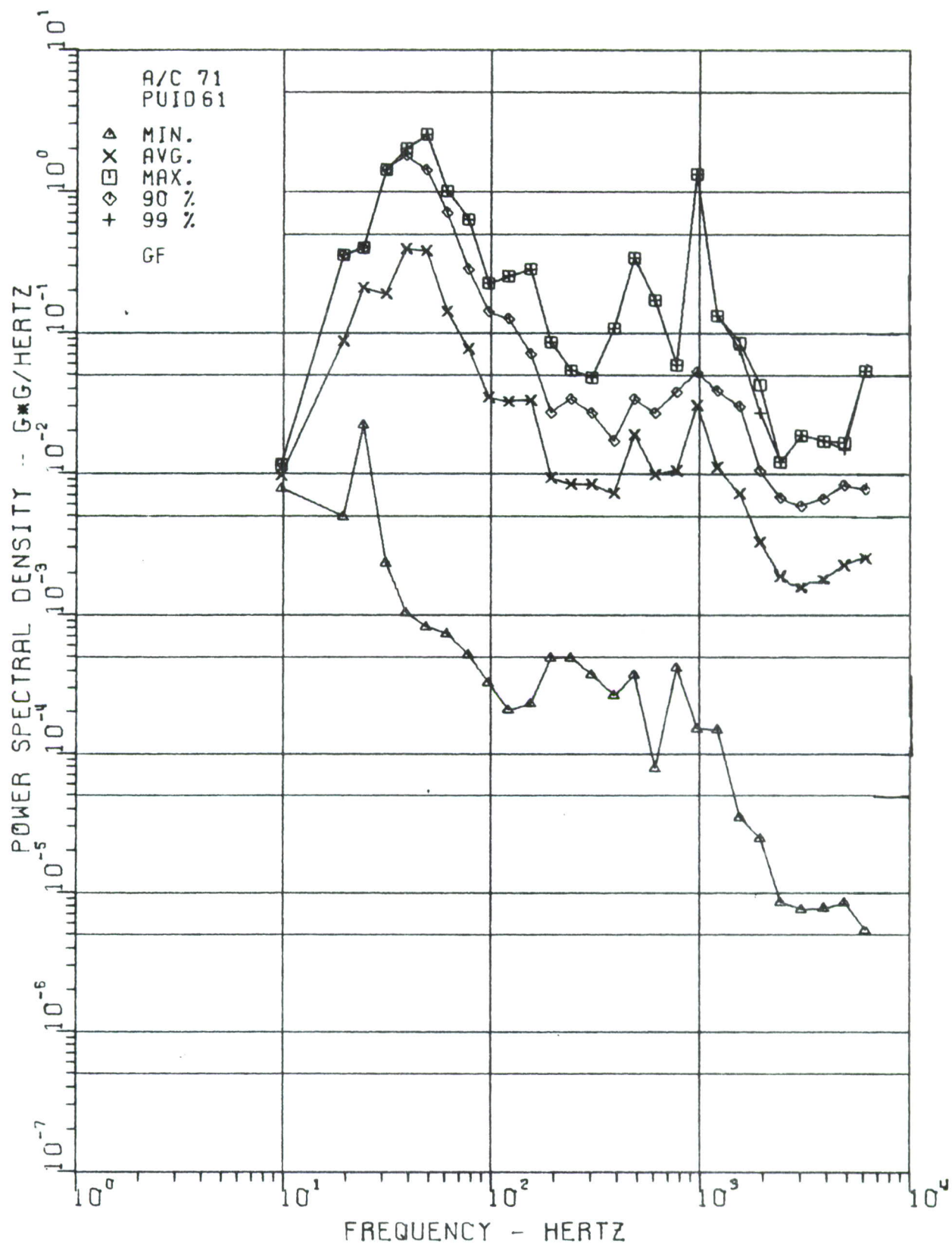


Figure 151. Aft Electrical Comp. near AN/ARN-83 Direction Finder,
Sta. 279, with Gunfire

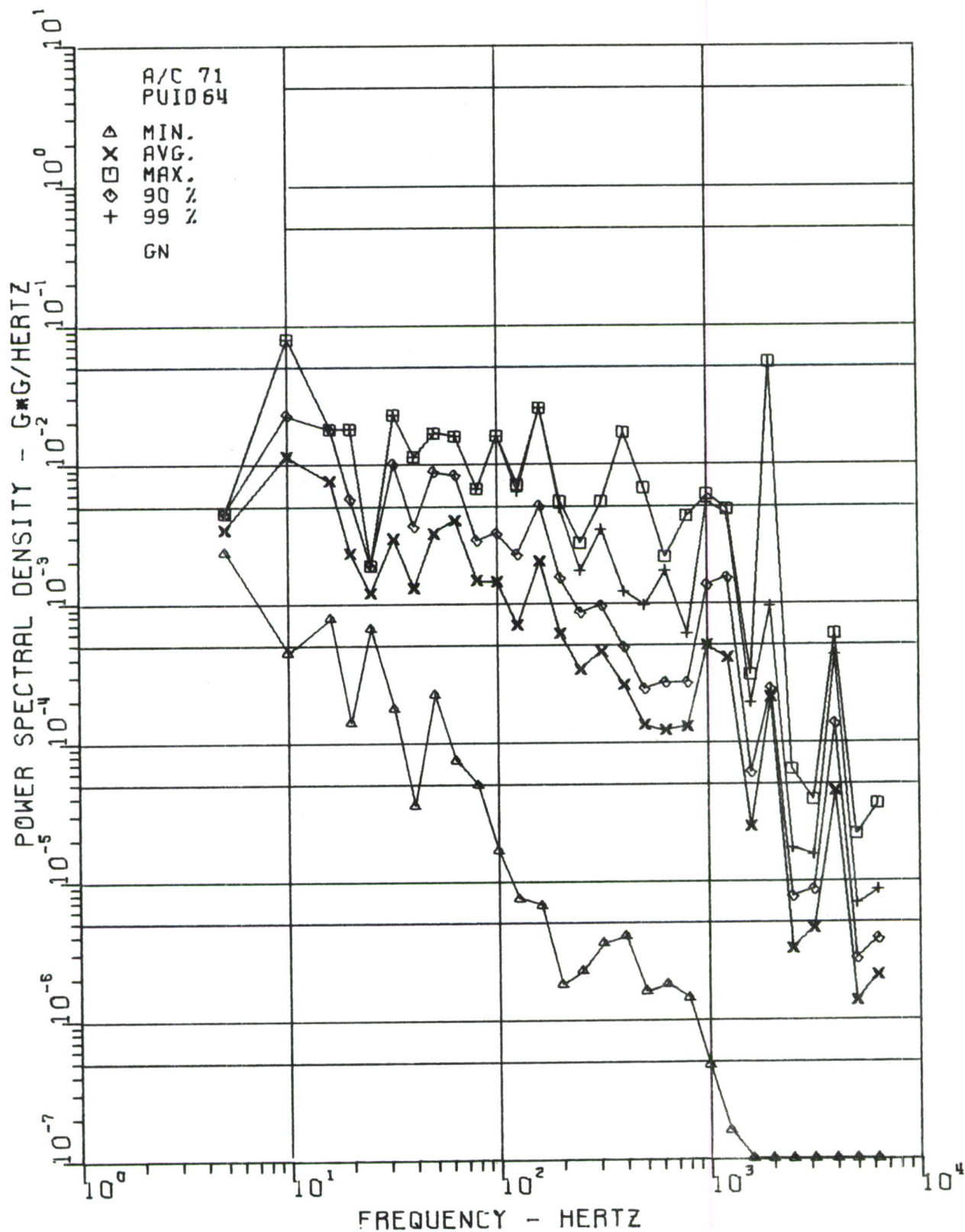


Figure 152. Aft Electrical Comp. near AN/ASN-43 Gyro
Compass, Sta. 291

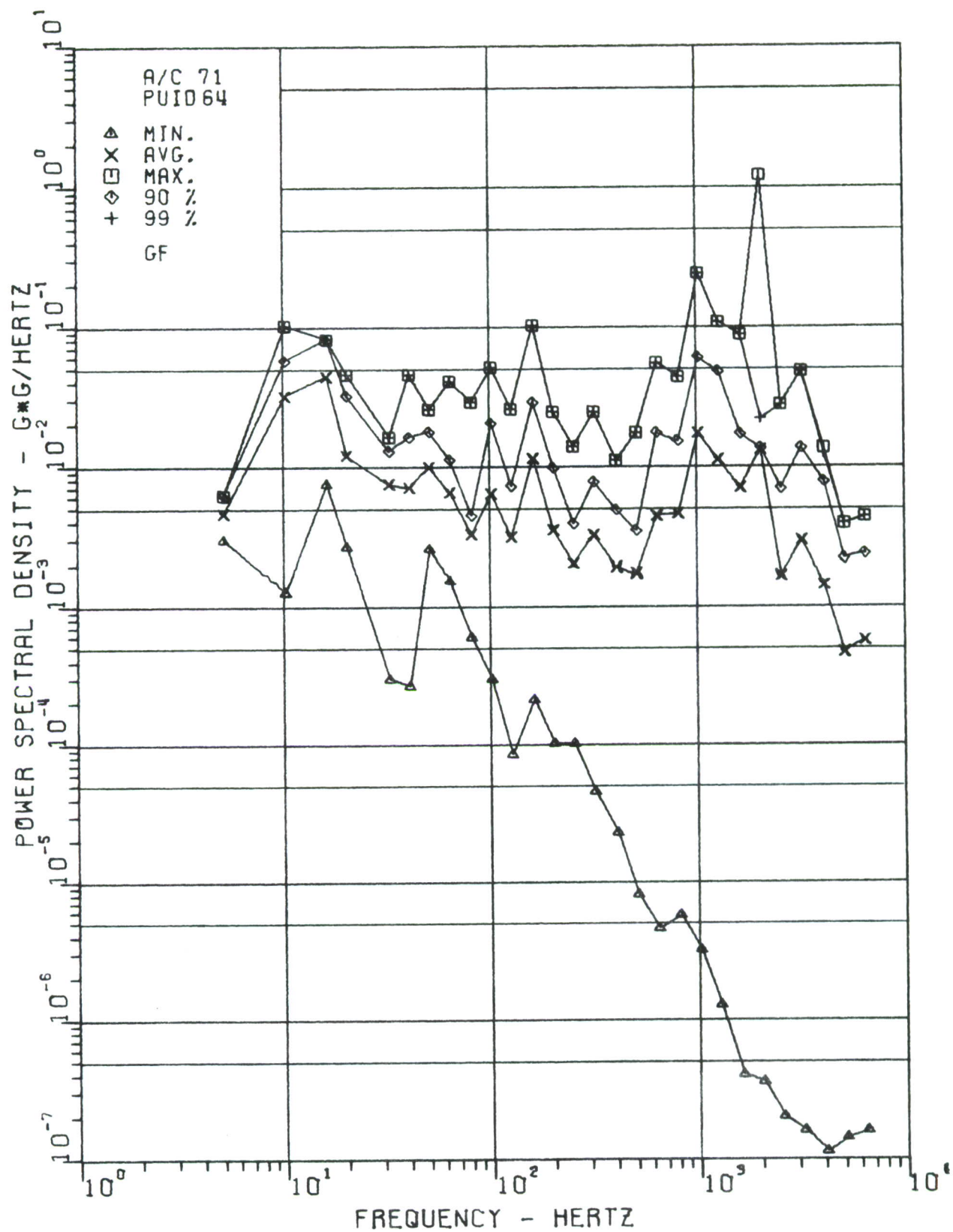


Figure 153. Aft Electrical Comp. near AN/ASN-43 Gyro Compass, Sta. 291,
with Gunfire

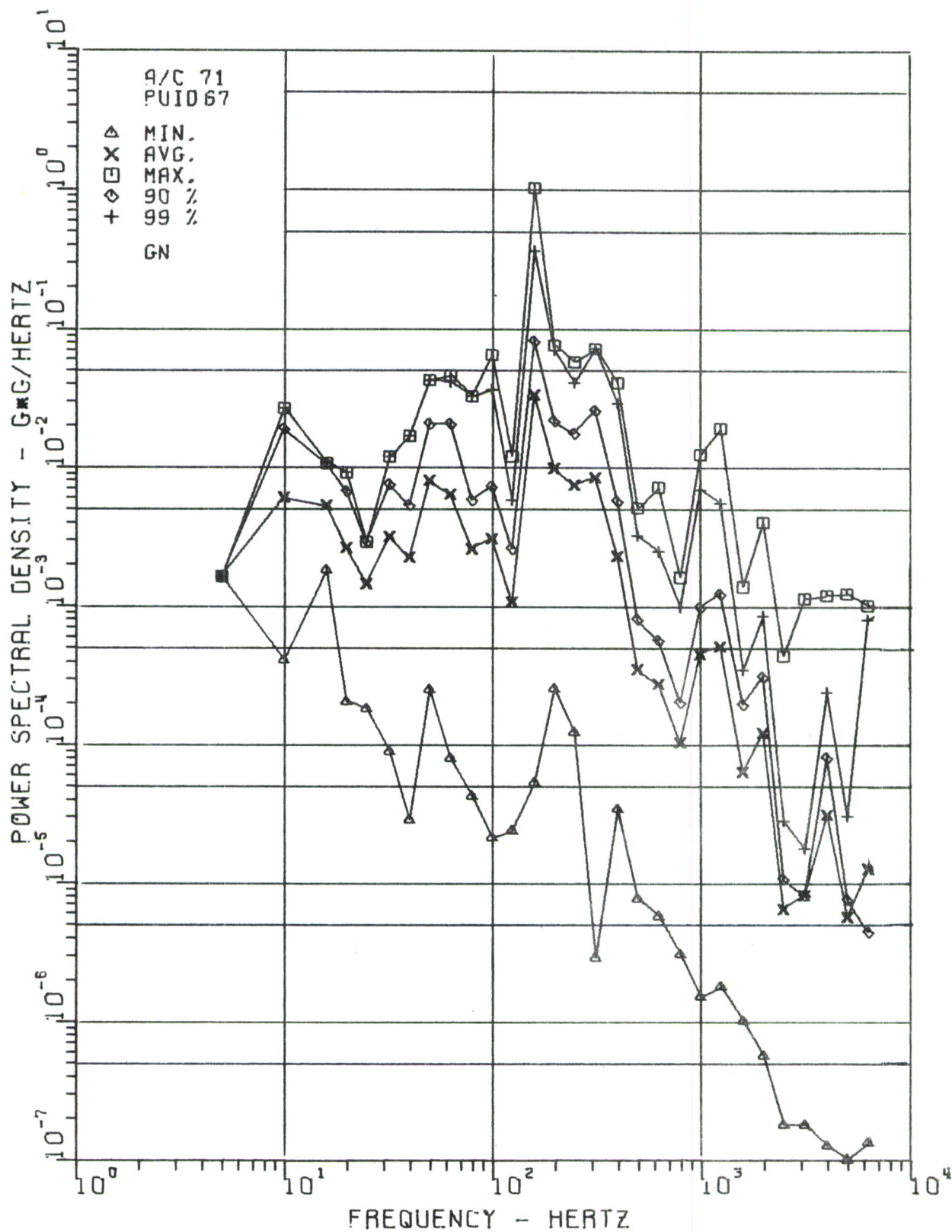


Figure 154. Structure near AN/APX-72 Transponder, Sta. 330

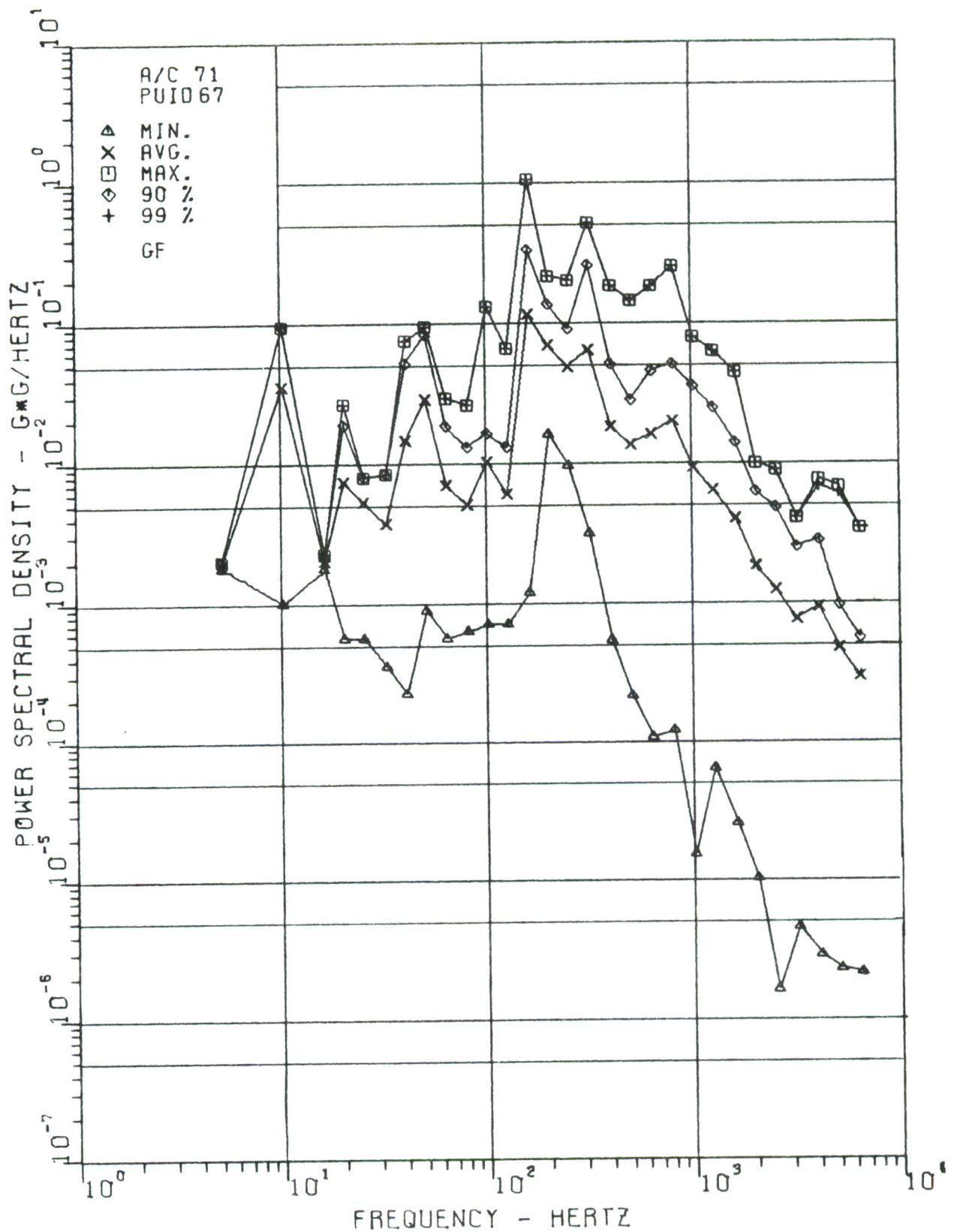


Figure 155. Structure near AN/APX-72 Transponder, Sta. 330,
with Gunfire

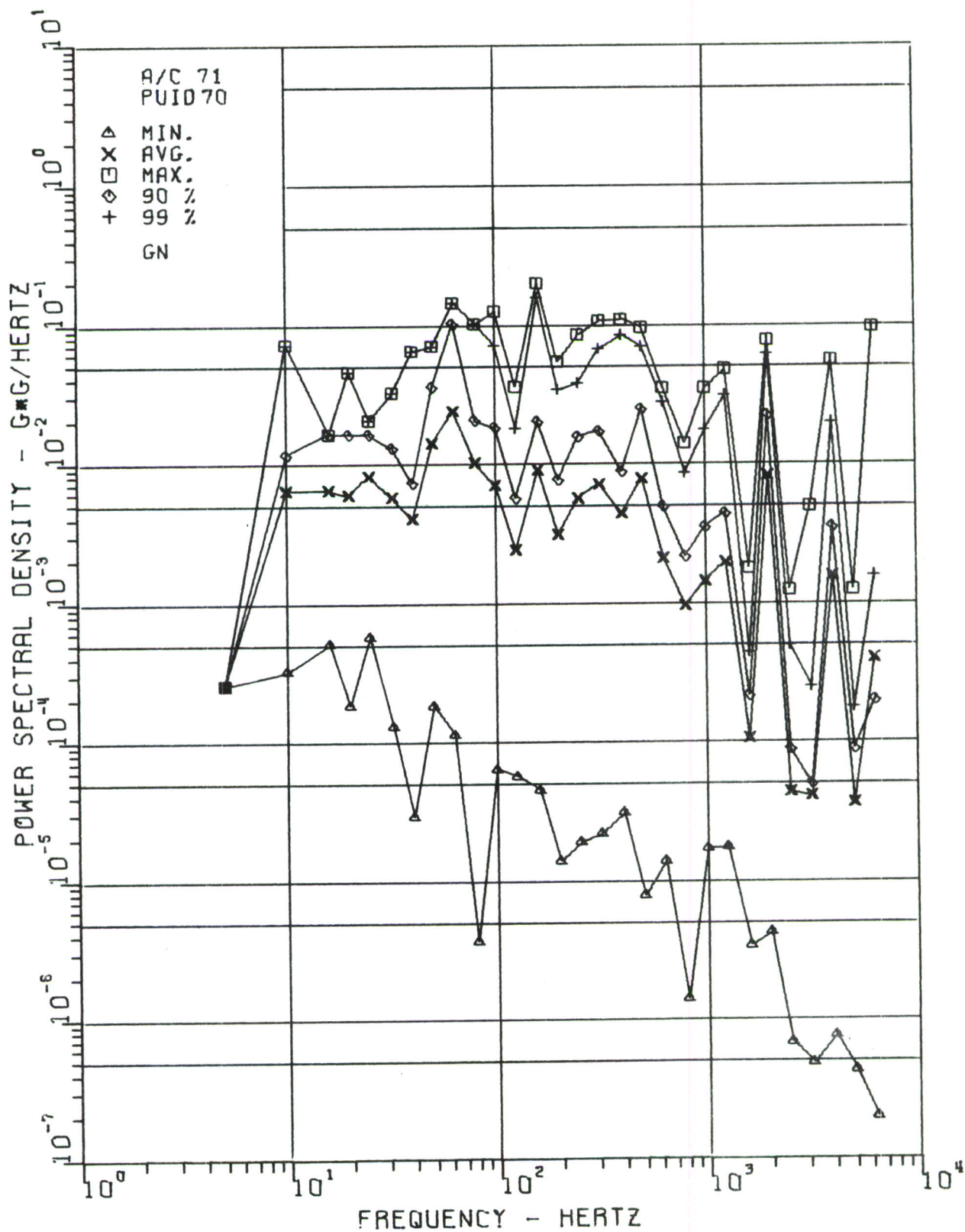


Figure 156. Tail Boom. Sta. 400

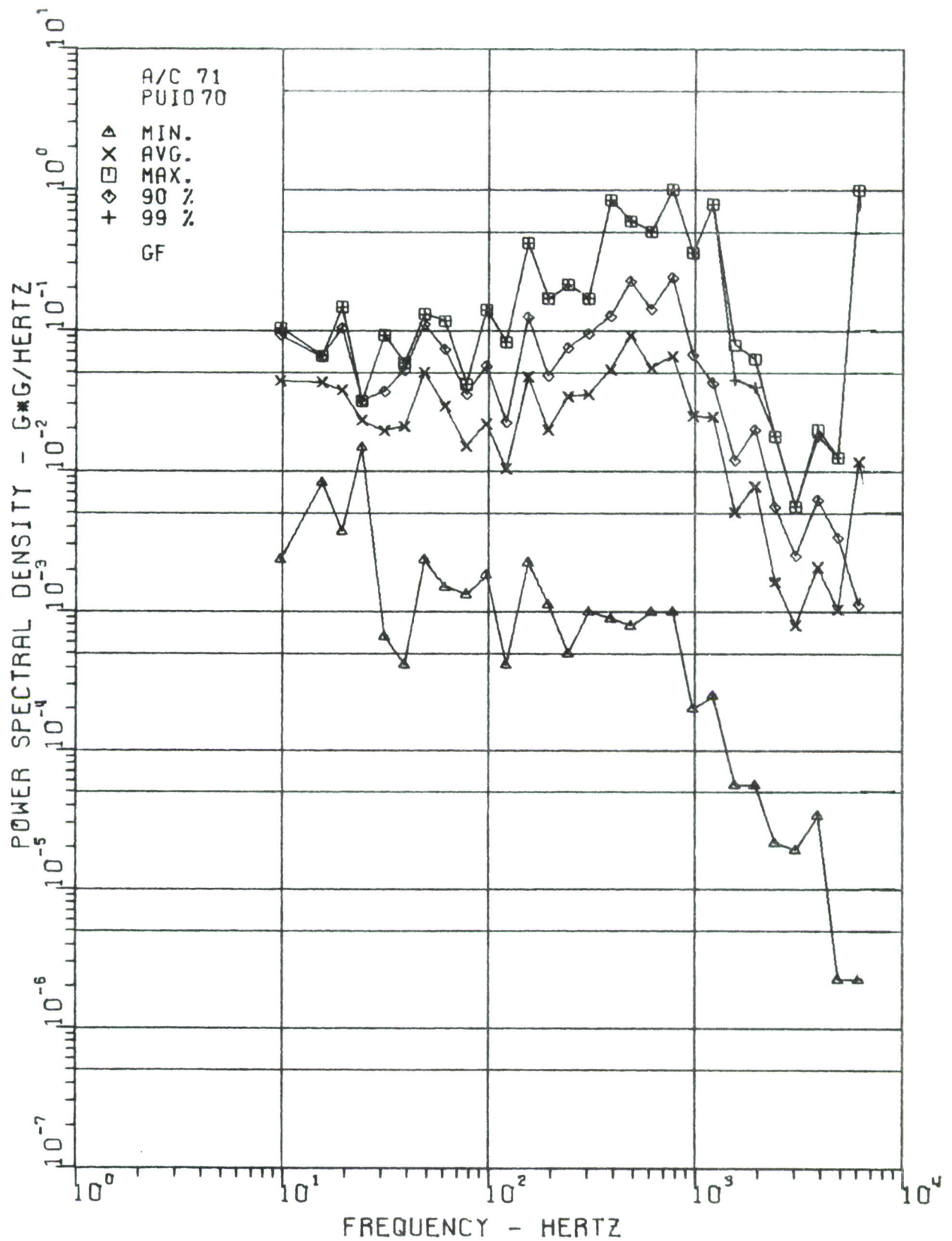


Figure 157. Tail Boom, Sta. 400, with Gunfire

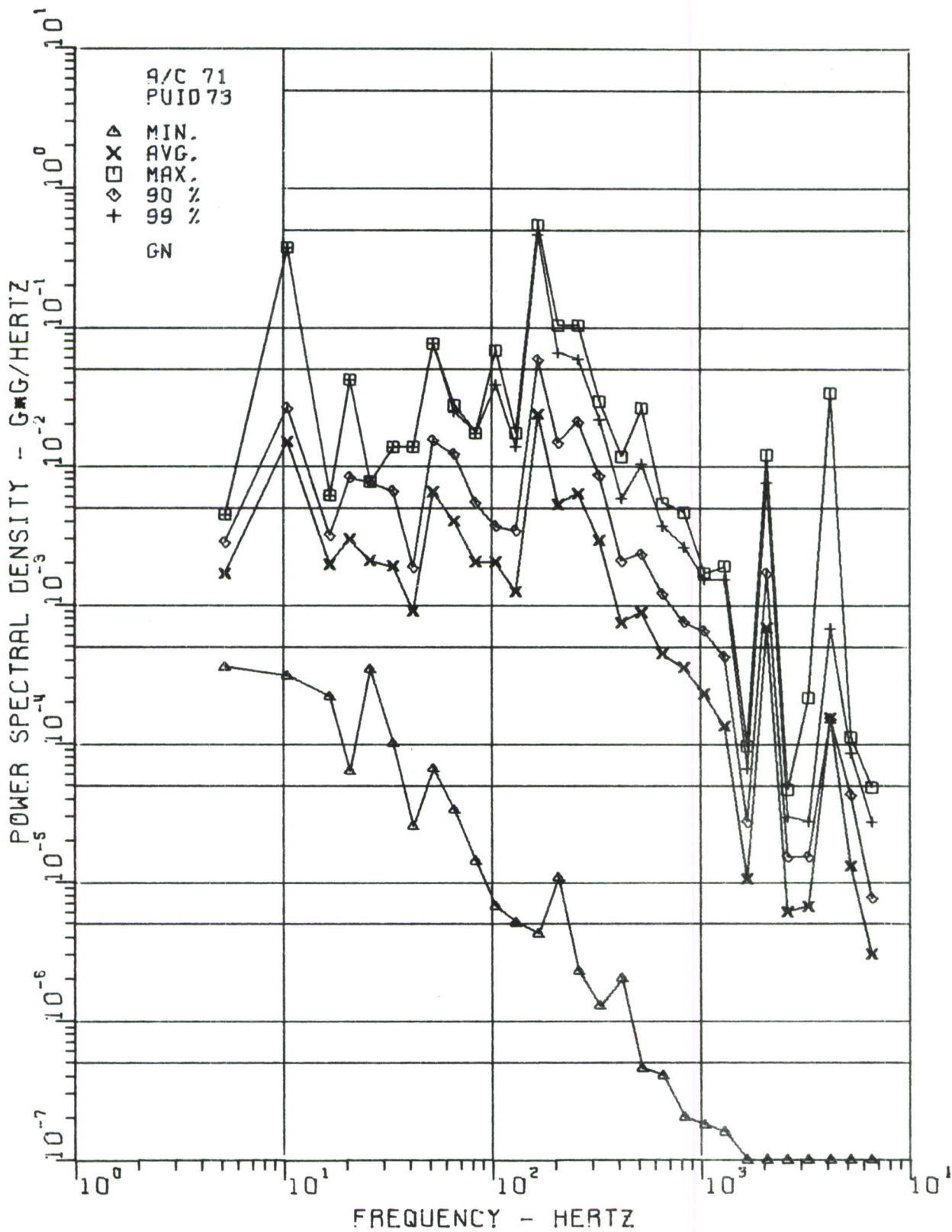


Figure 158. Radio Compartment near AN/ARC-51 Transceiver, Sta. 346

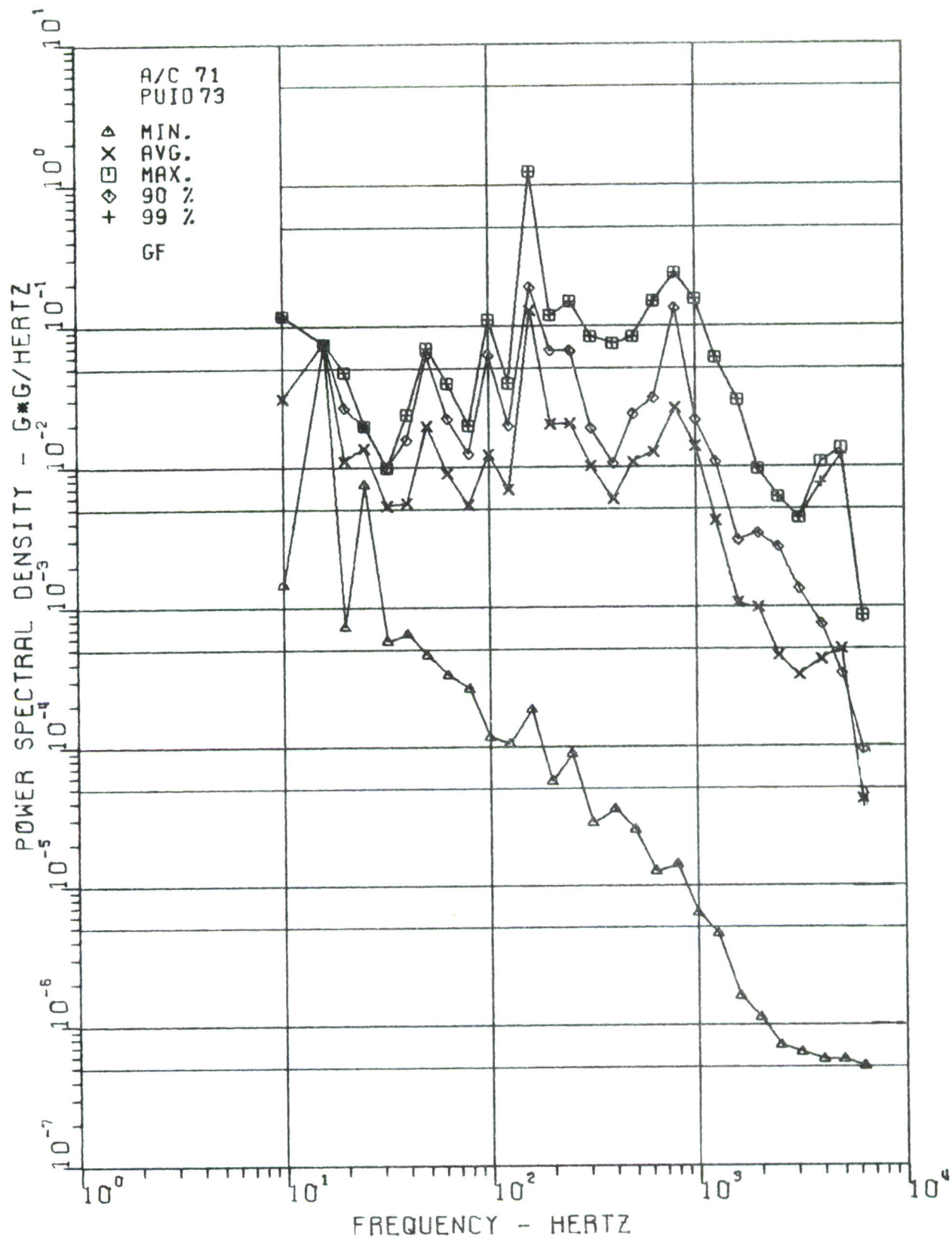


Figure 159. Radio Compartment near AN/ARC-51 Transceiver, Sta. 346,
with Gunfire

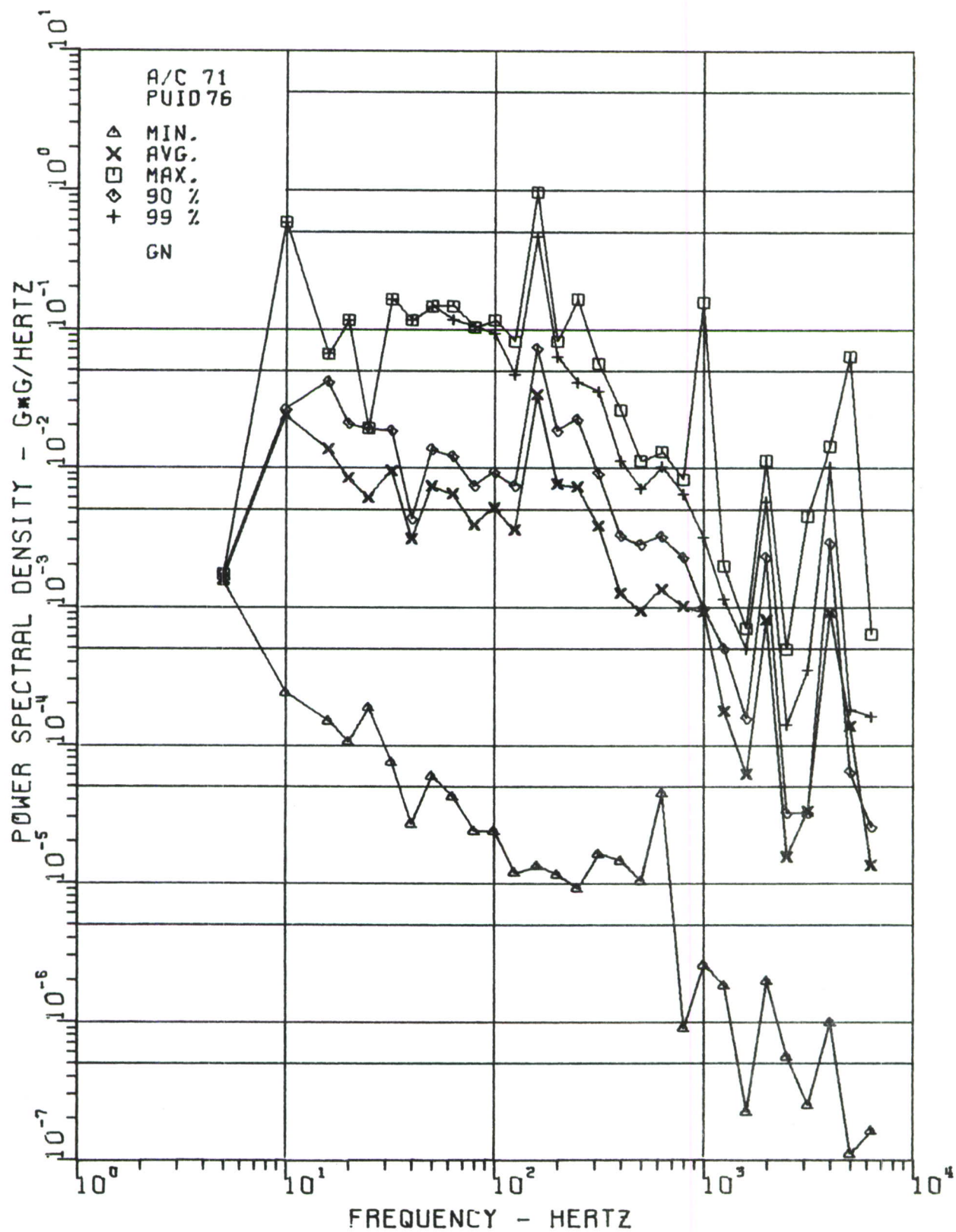


Figure 160. Radio Compartment near AN/ARC-134 Transceiver, Sta 364

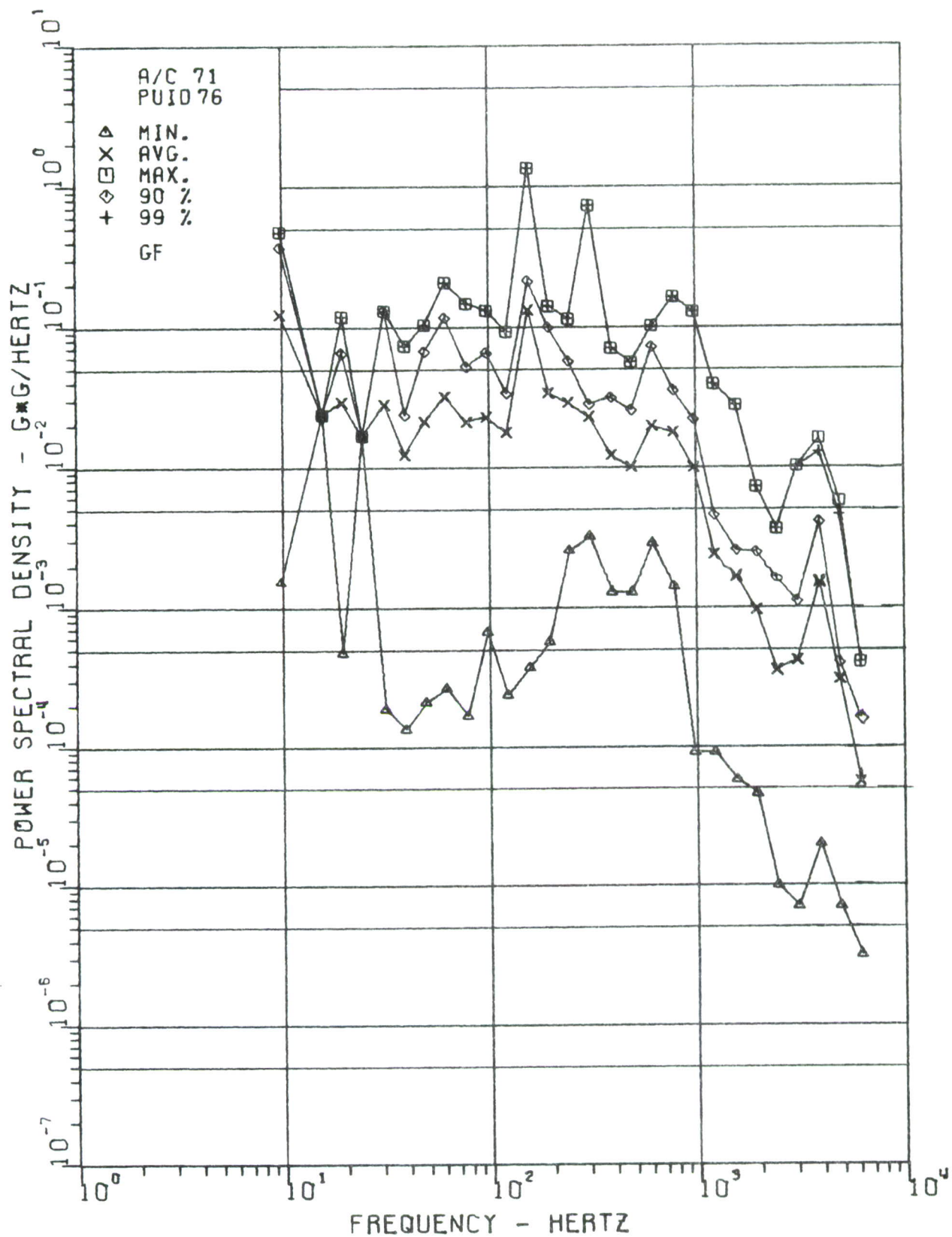


Figure 161. Radio Compartment near AN/ARC-134 Transceiver, Sta. 364 with Gunfire

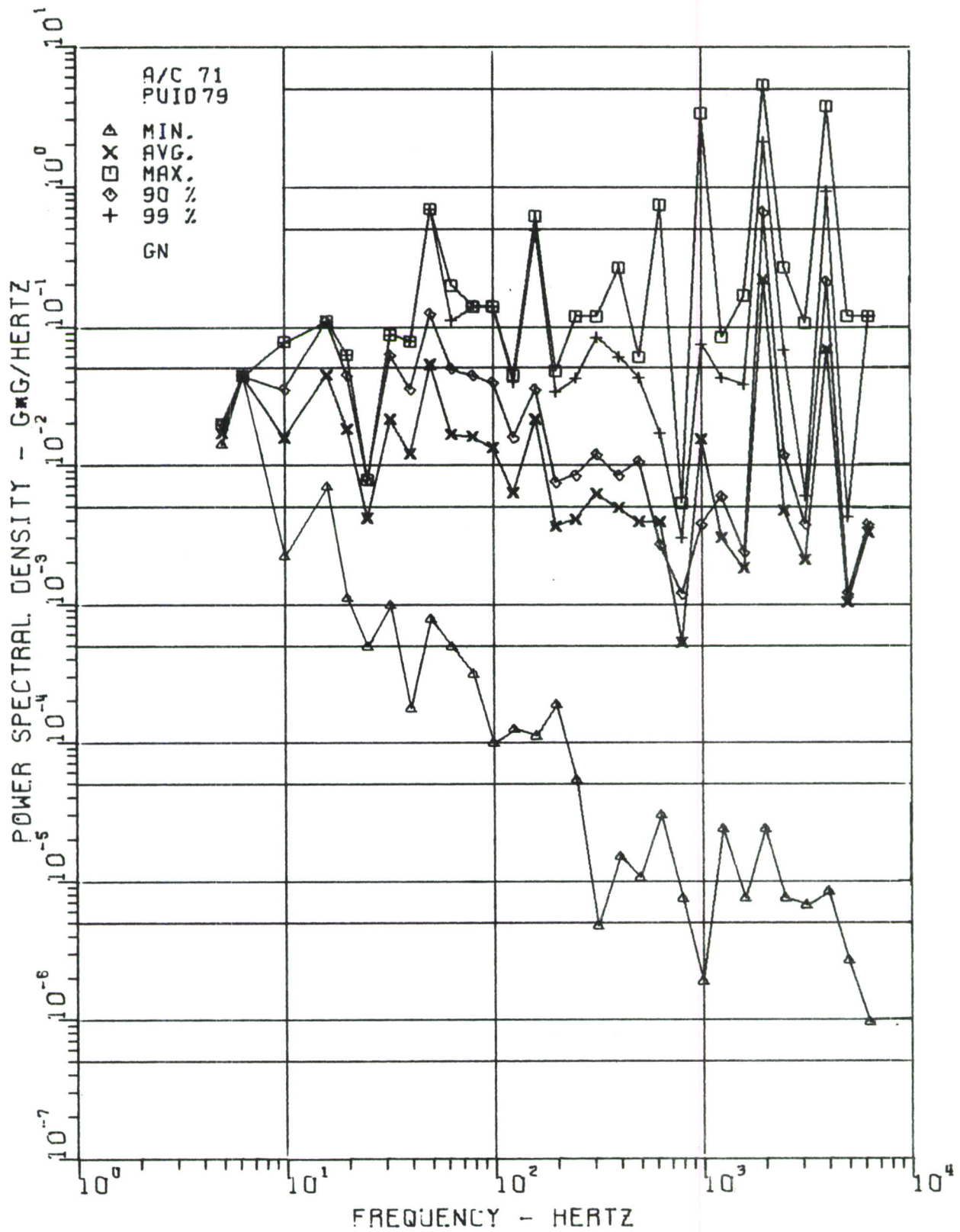


Figure 162. Tail Boom near 45° Gear Box, Sta. 470

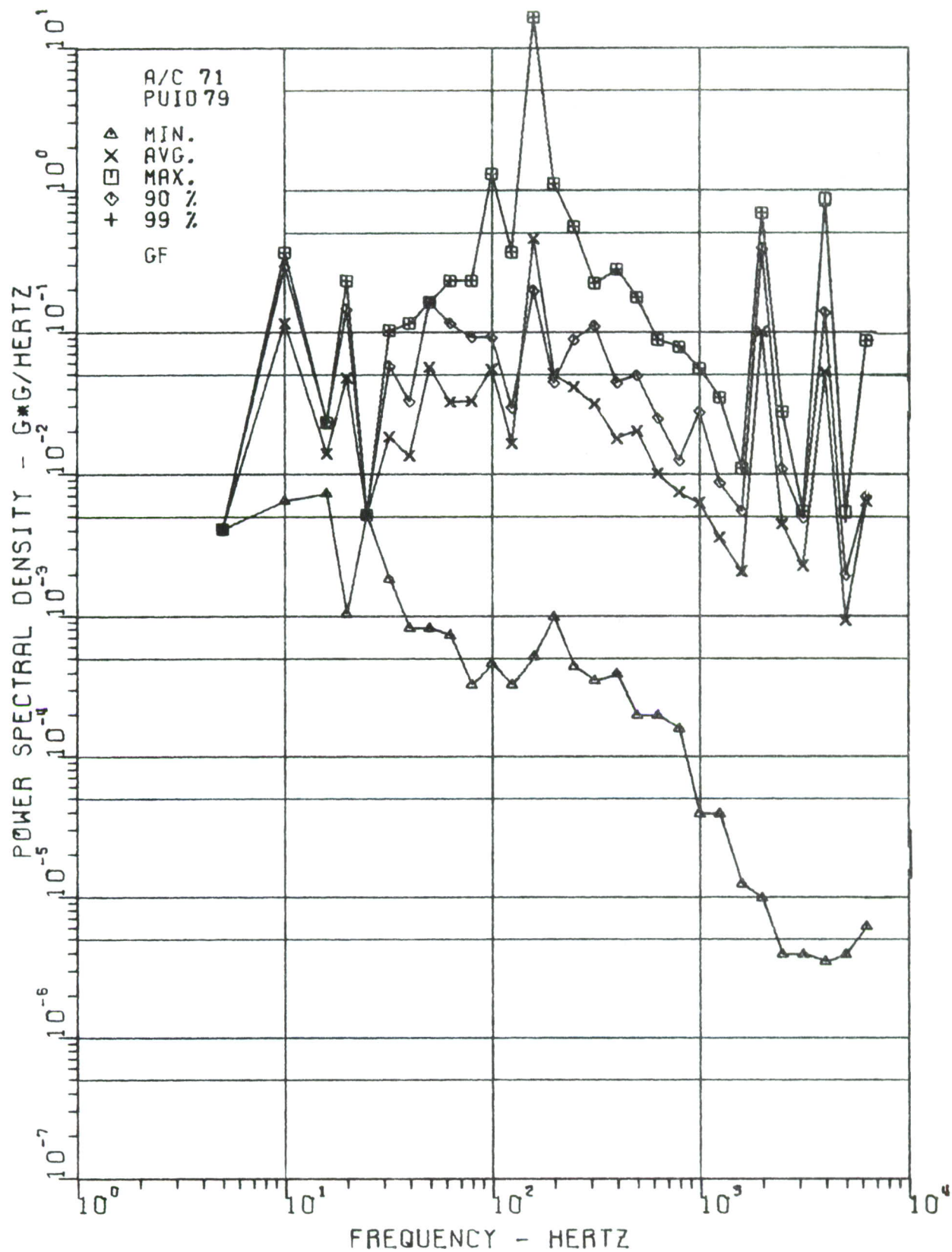


Figure 163. Tail Boom near 45° Gear Box, Sta. 470, with Gunfire

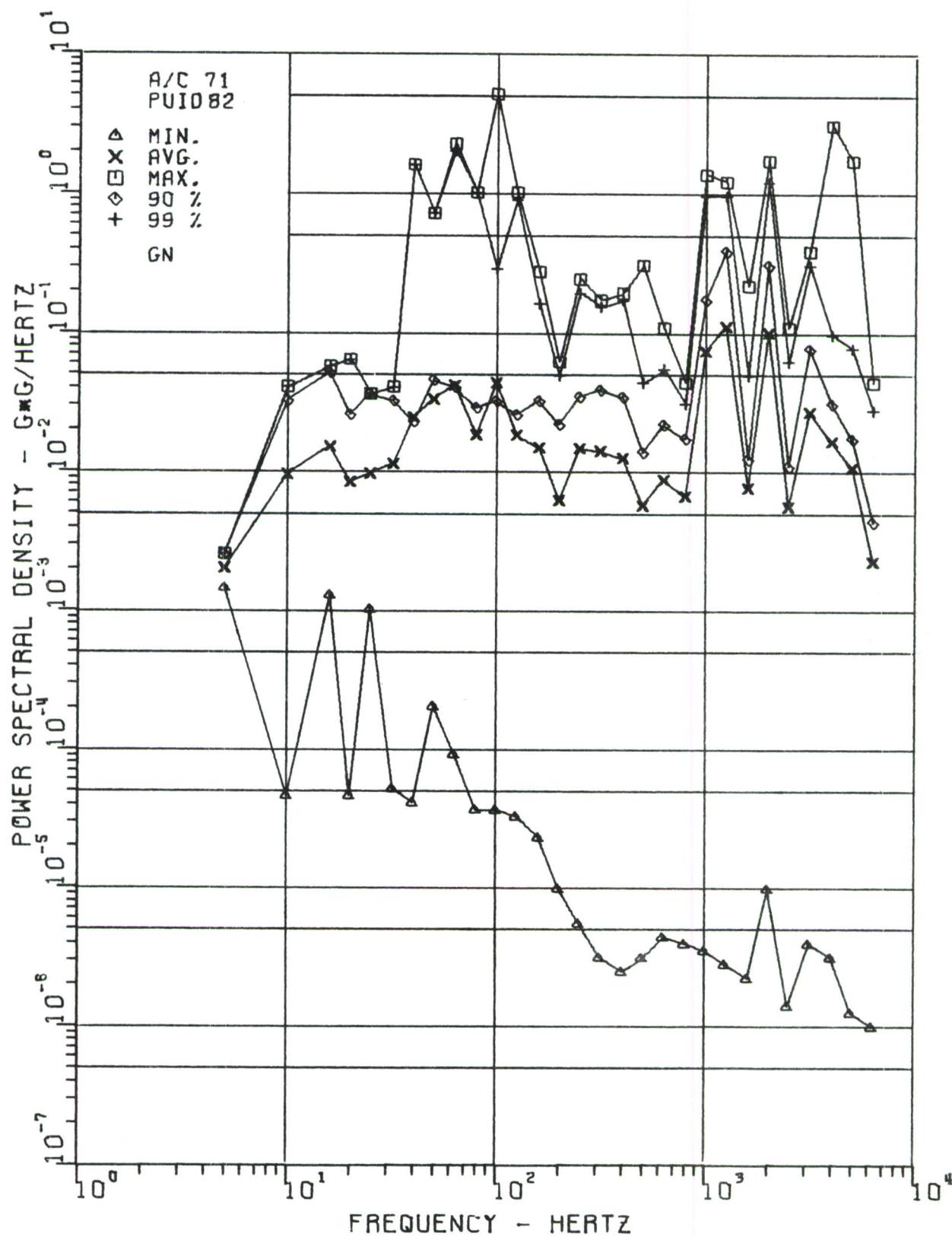


Figure 164. Tail Boom near 90° Gear Box, Sta. 520

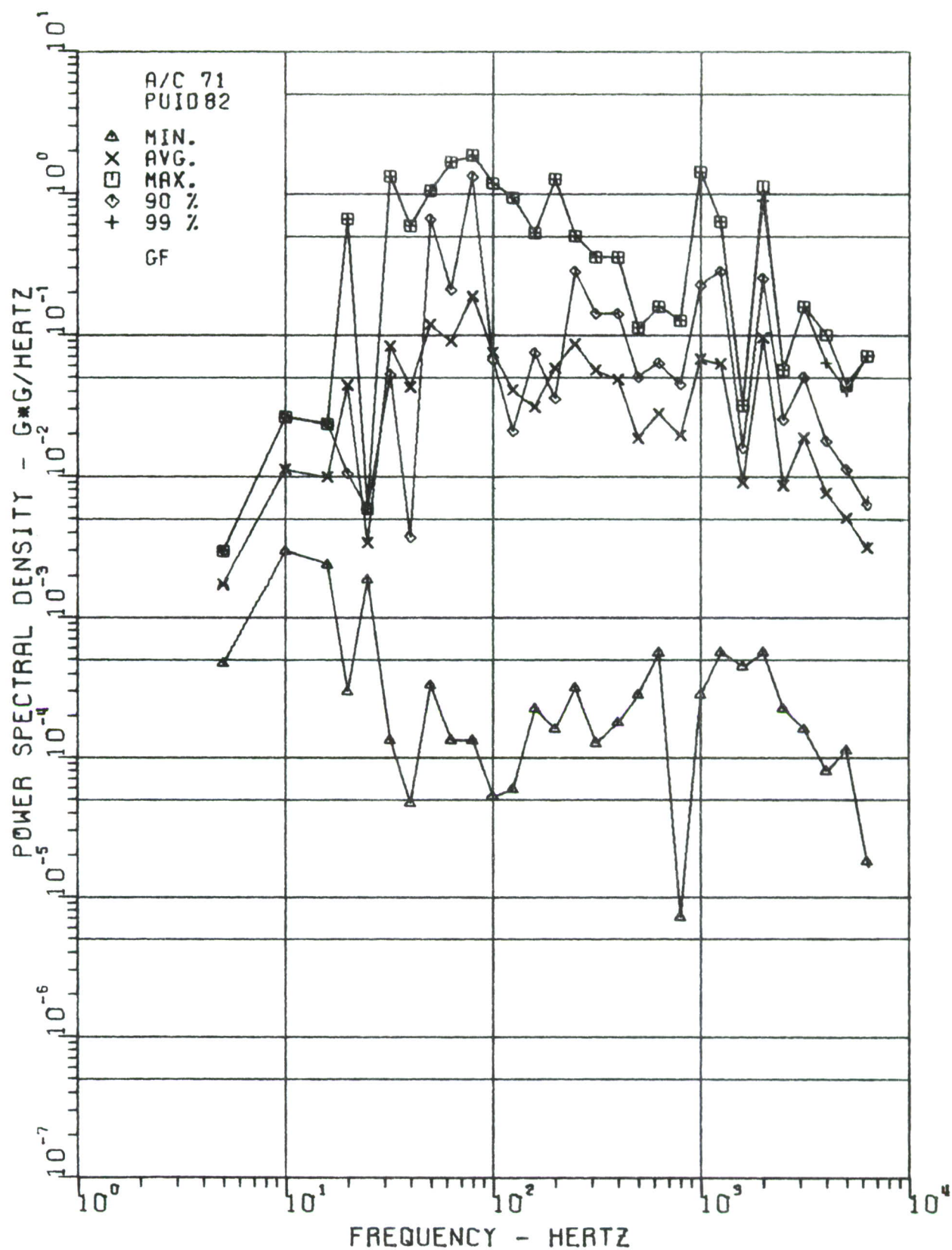


Figure 165. Tail Boom near 90° Gear Box, Sta. 520, with Gunfire

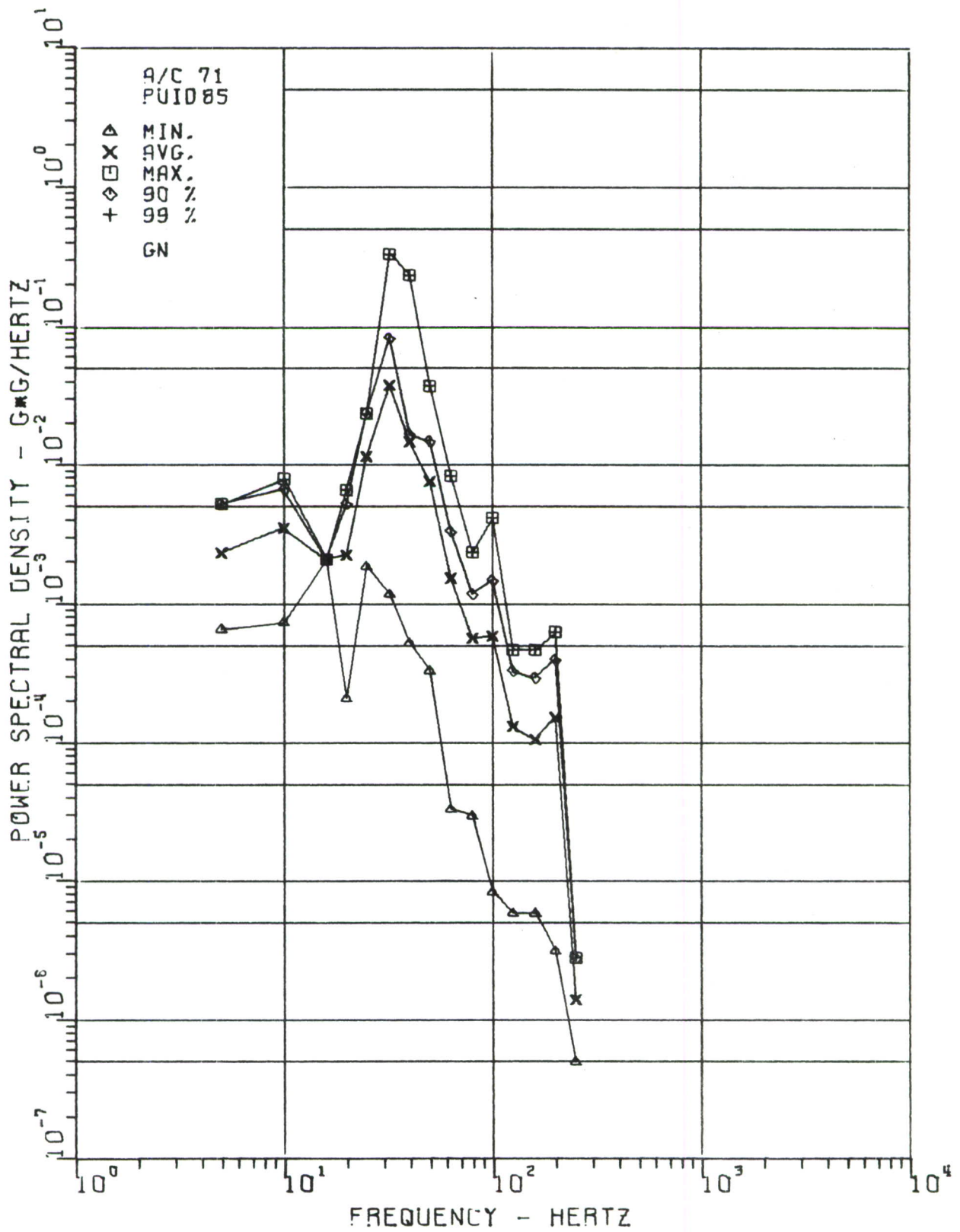


Figure 166. Gunner's Instr. Panel, Left Side, Sta. 60

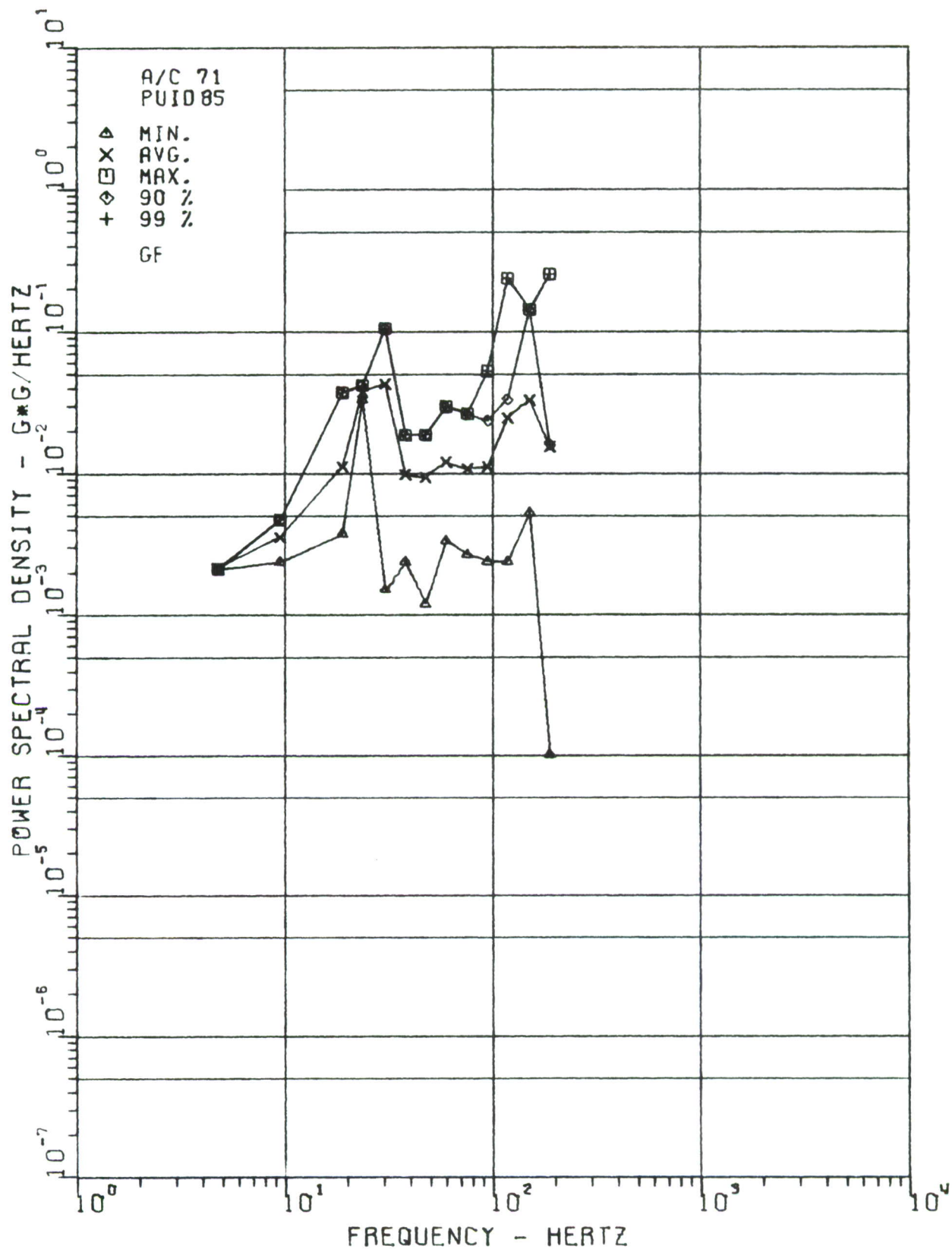


Figure 167. Gunner's Instr. Panel, Left Side, Sta. 60, with Gunfire

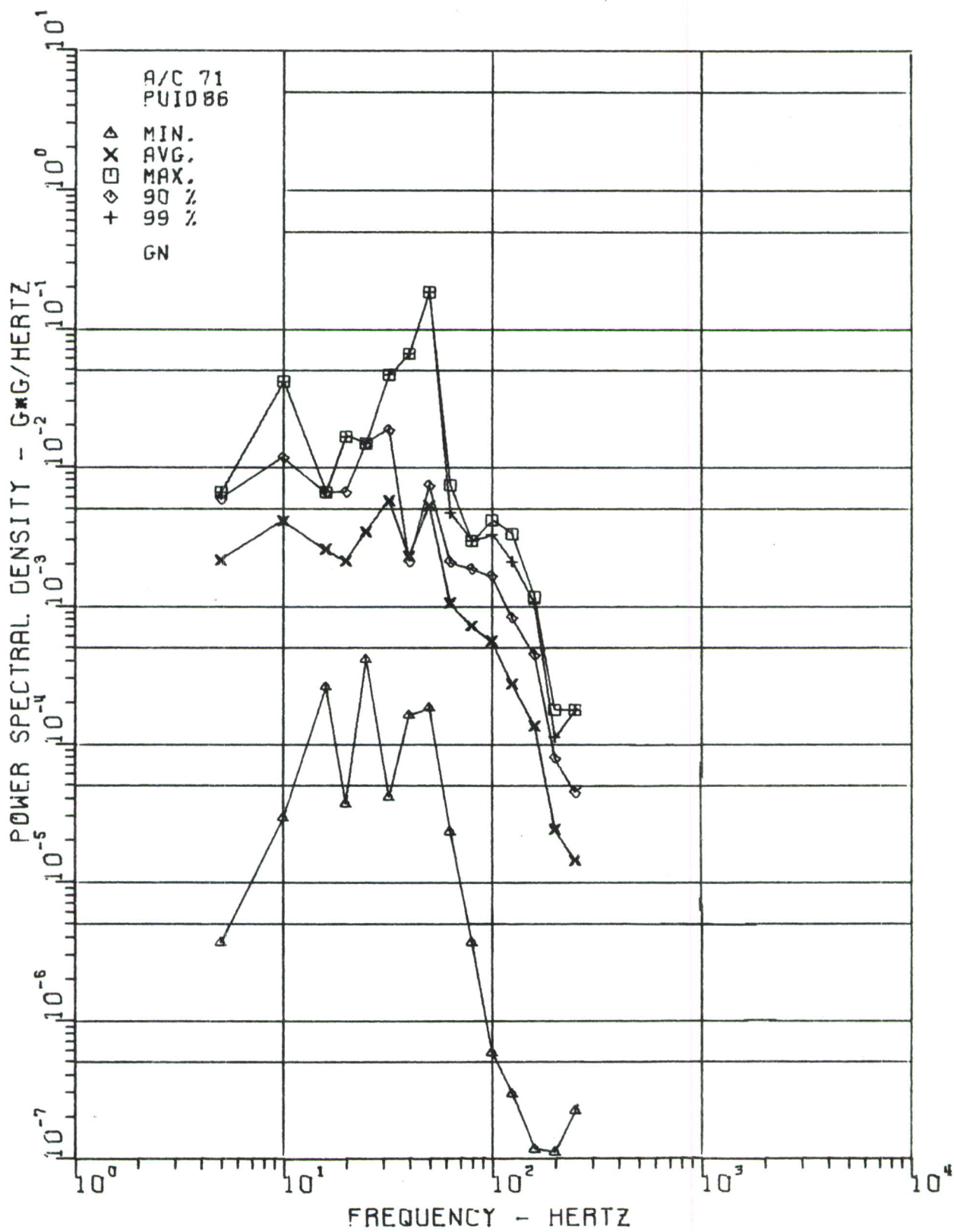


Figure 168. Gunner's Floor, Sta. 68

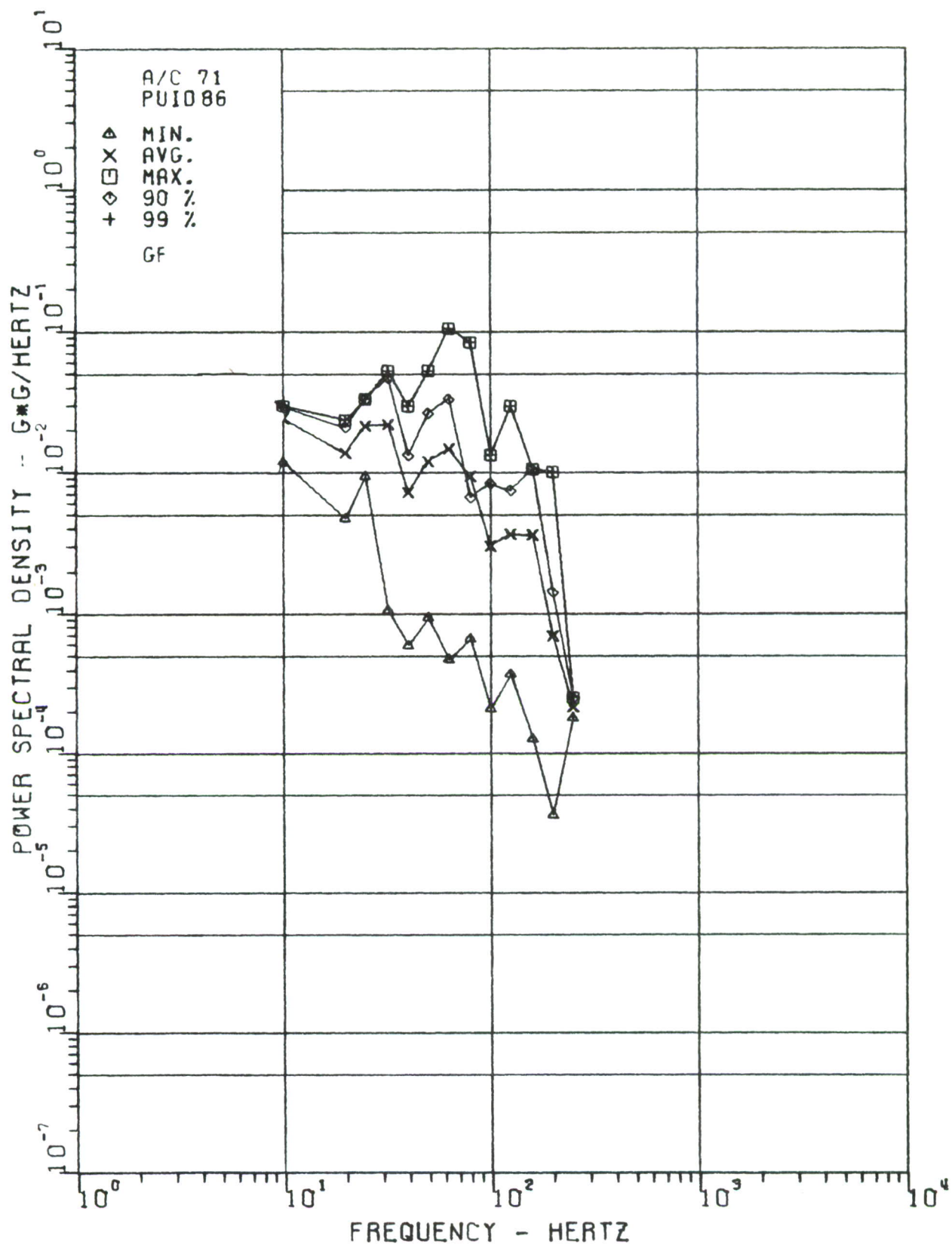


Figure 169. Gunner's Instrument Panel, Left Side, Sta. 68, with Gunfire

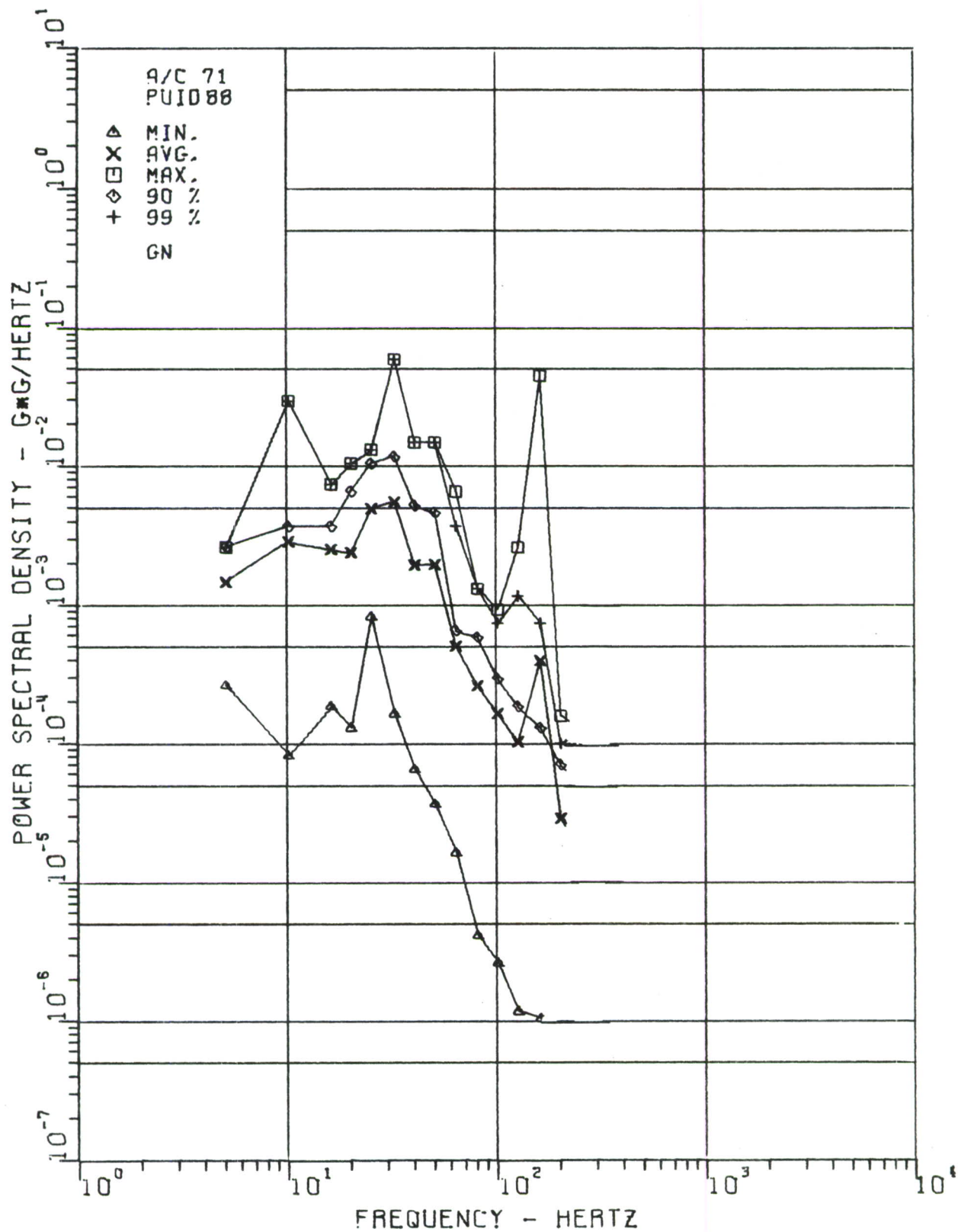


Figure 170. Pilot's Instr. Panel, Right Side, Sta. 115

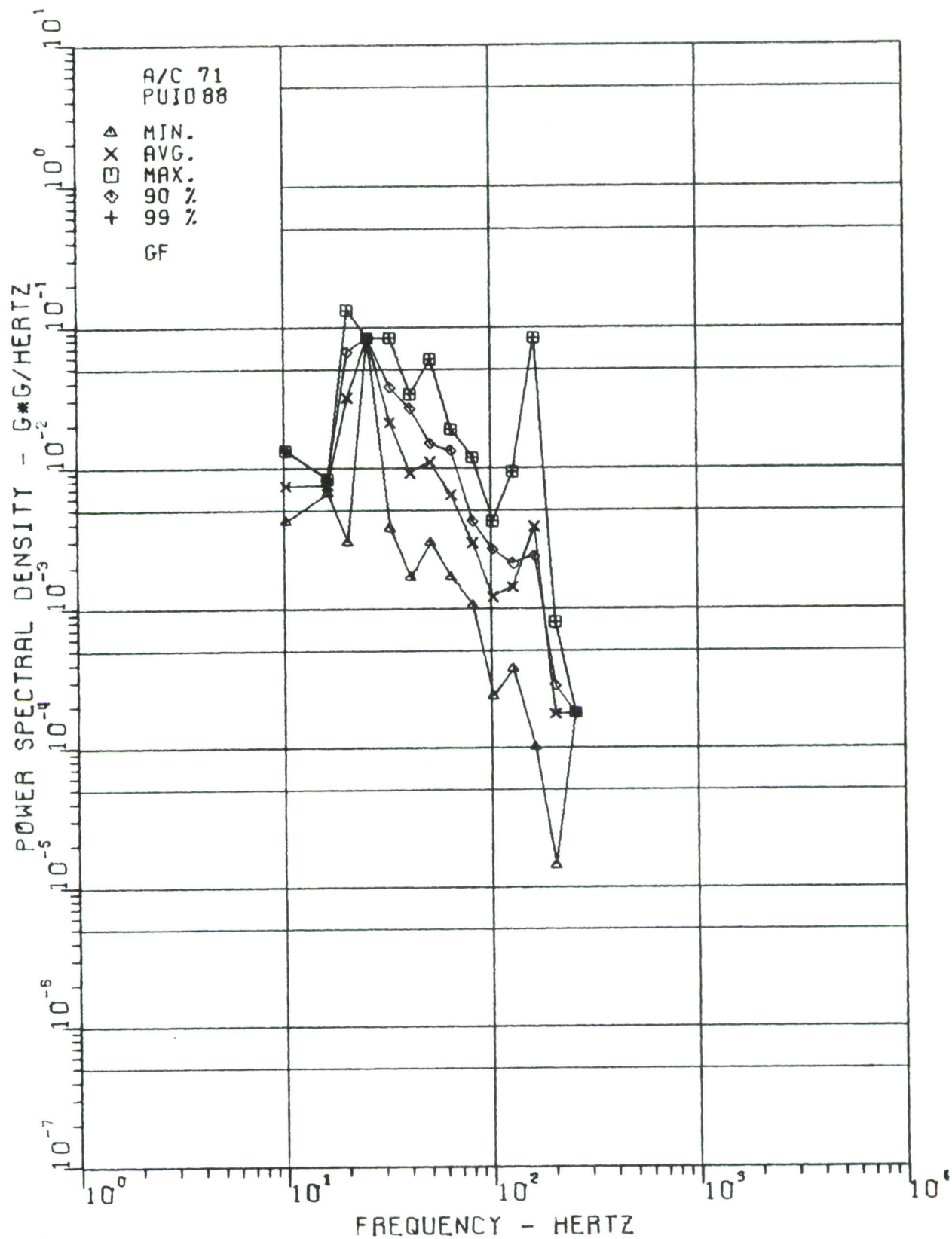


Figure 171. Pilot's Instrument Panel, Right Side, Sta. 115, with Gunfire

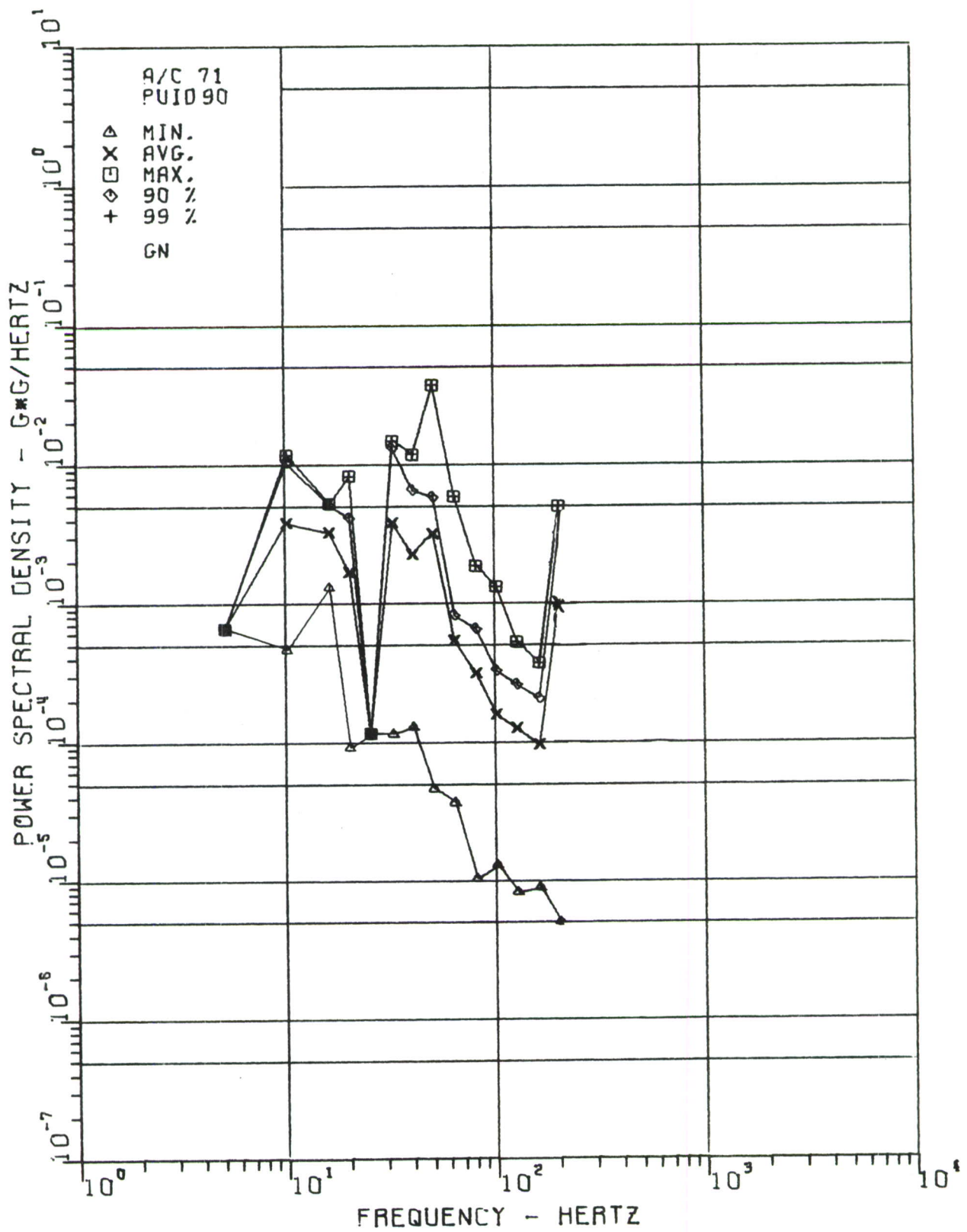


Figure 172. Pilot's Floor, Left Side, Sta. 134

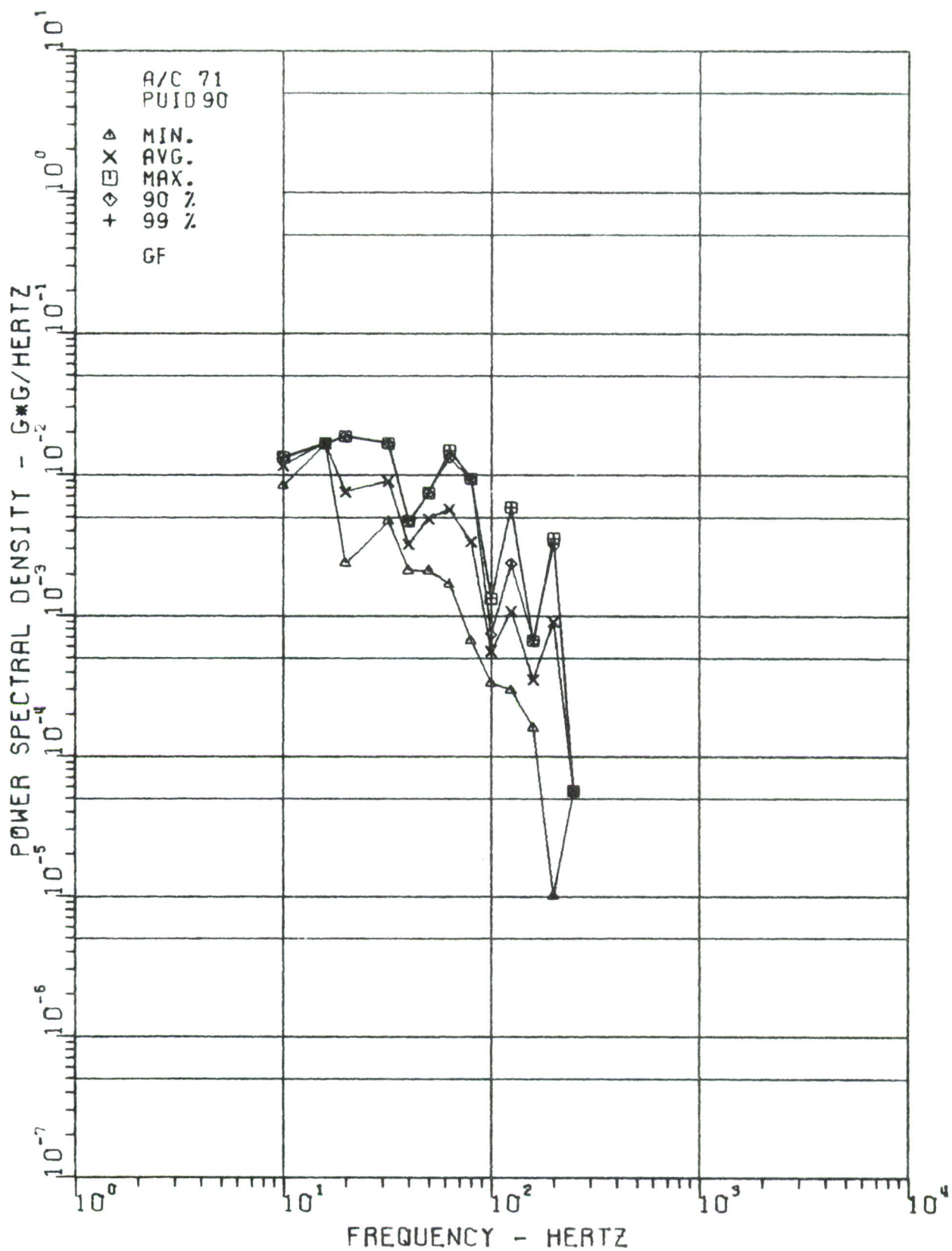


Figure 173. Pilot's Floor, Left Side, Sta. 134, with Gunfire

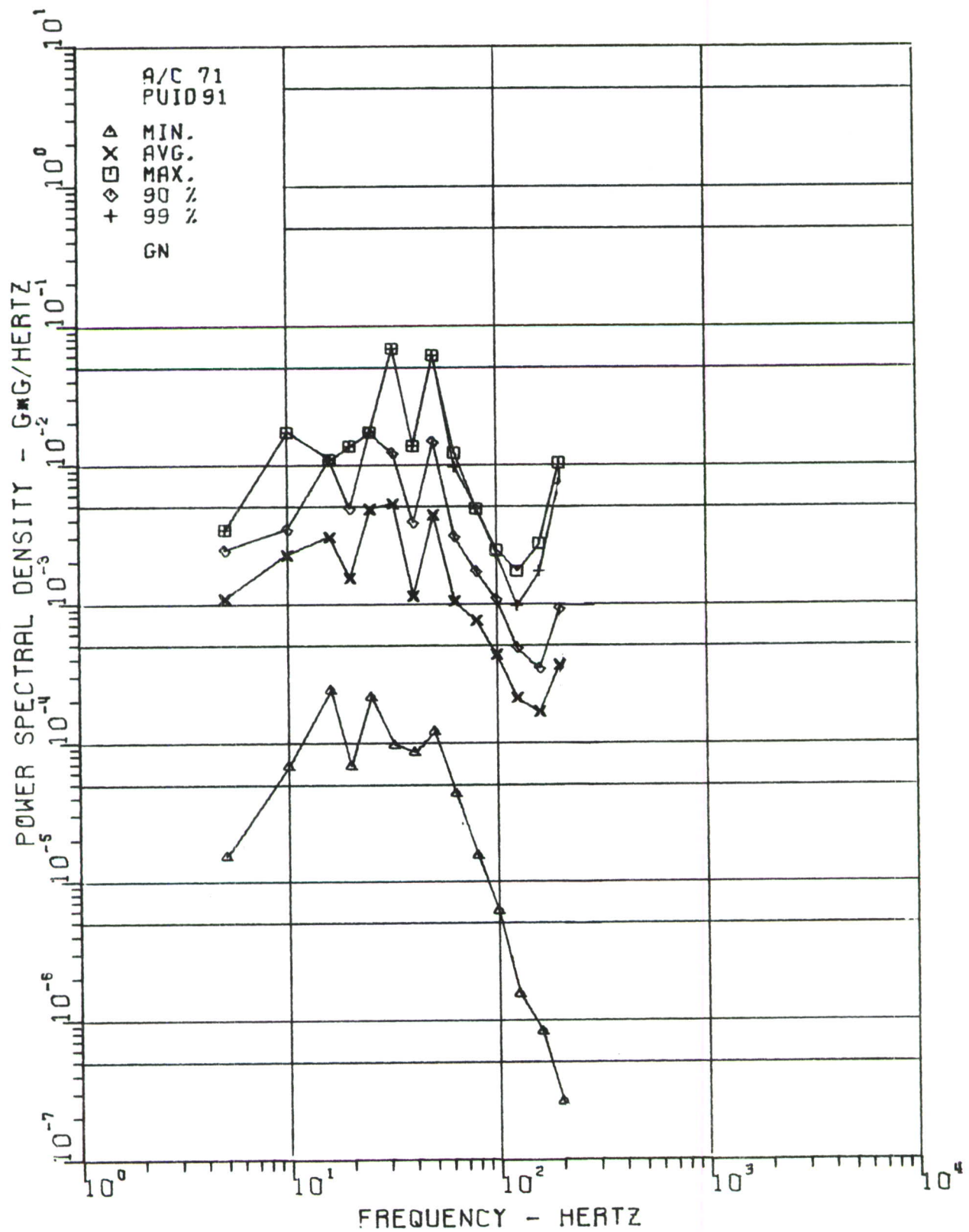


Figure 174. Pilot's Floor, Right Side, Sta. 134

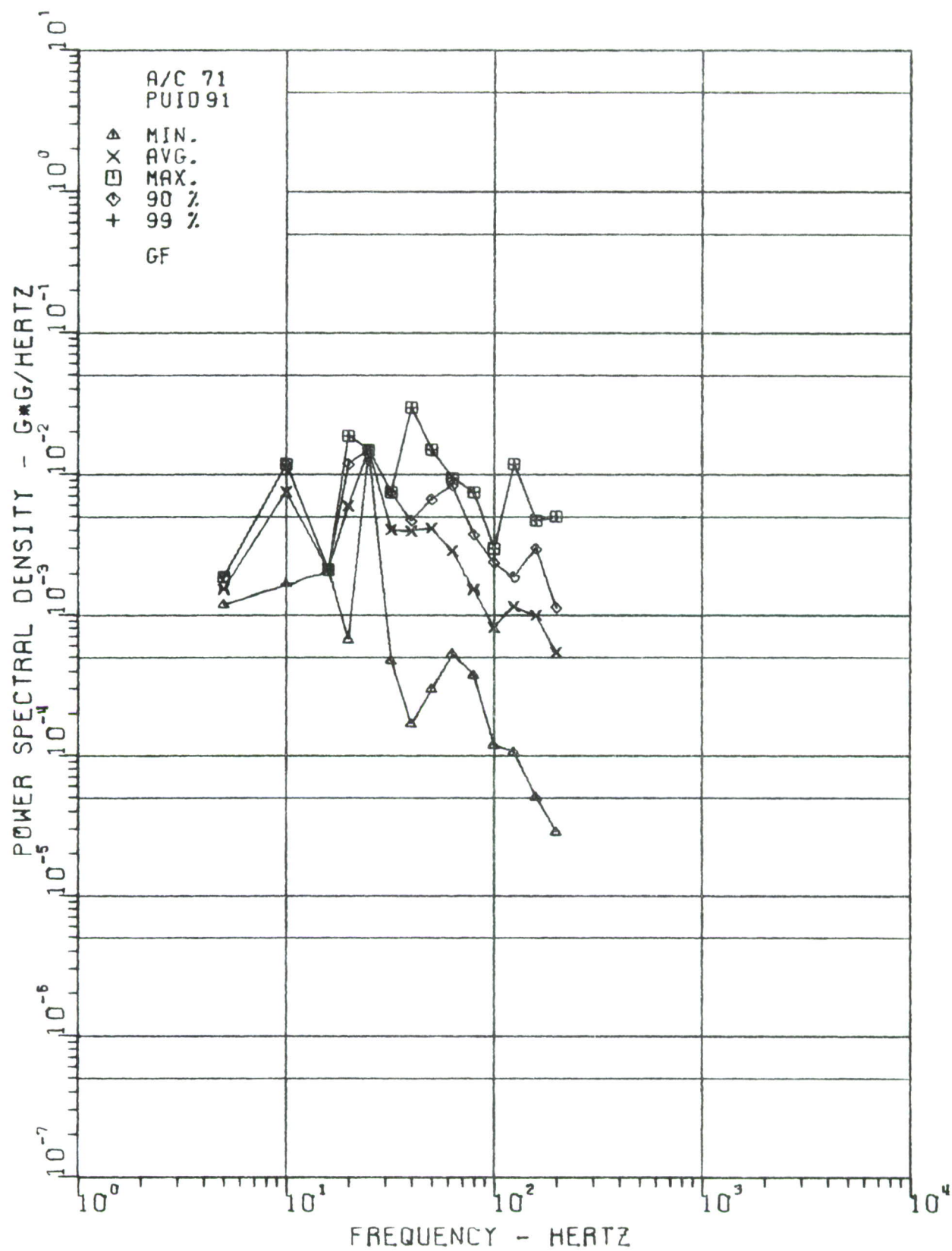


Figure 175. Pilot's Floor, Right Side, Sta. 134, with Gunfire

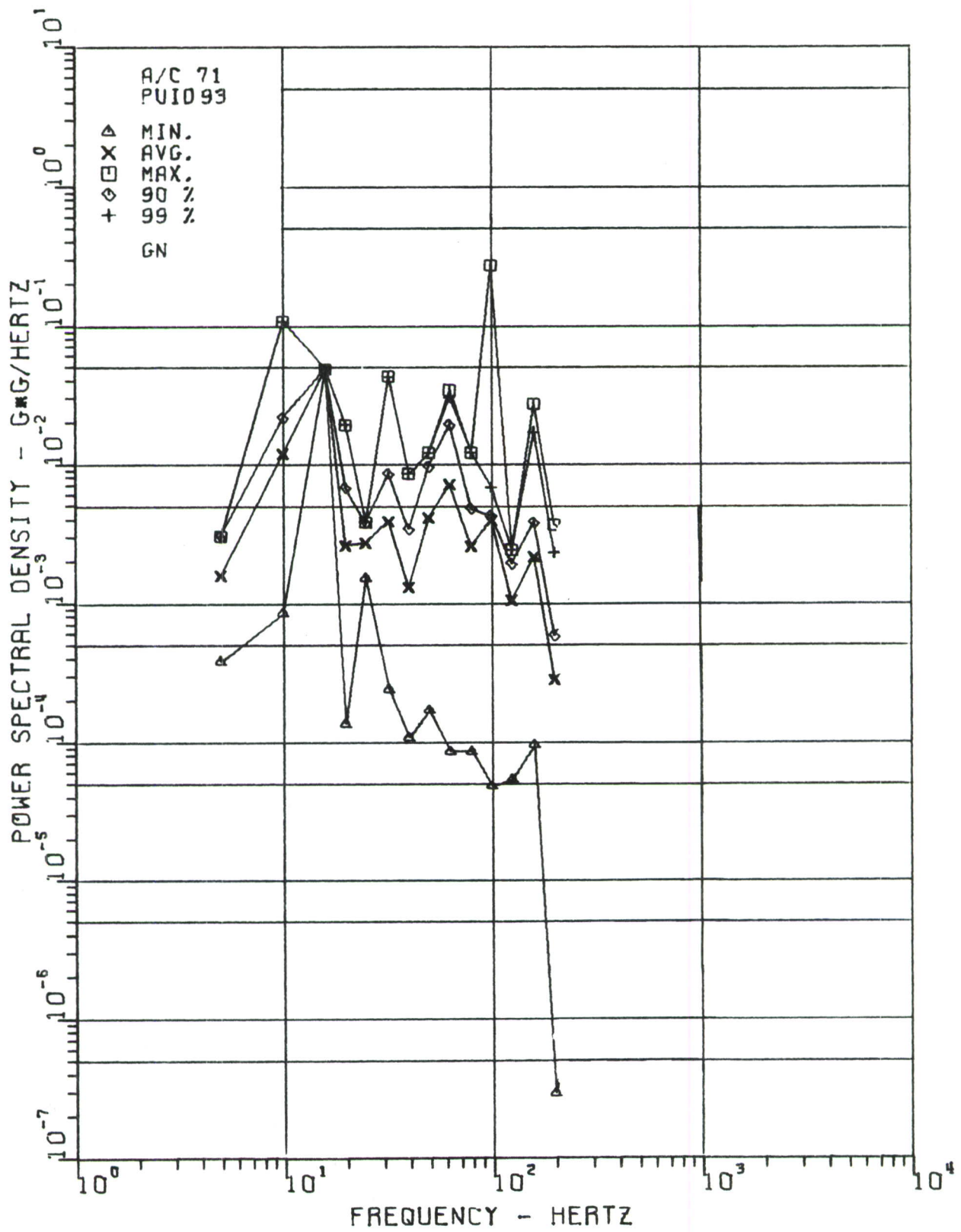


Figure 176. Aft Electrical Comp. near AN/ASN-43 Gyro
 Compass, Sta. 284

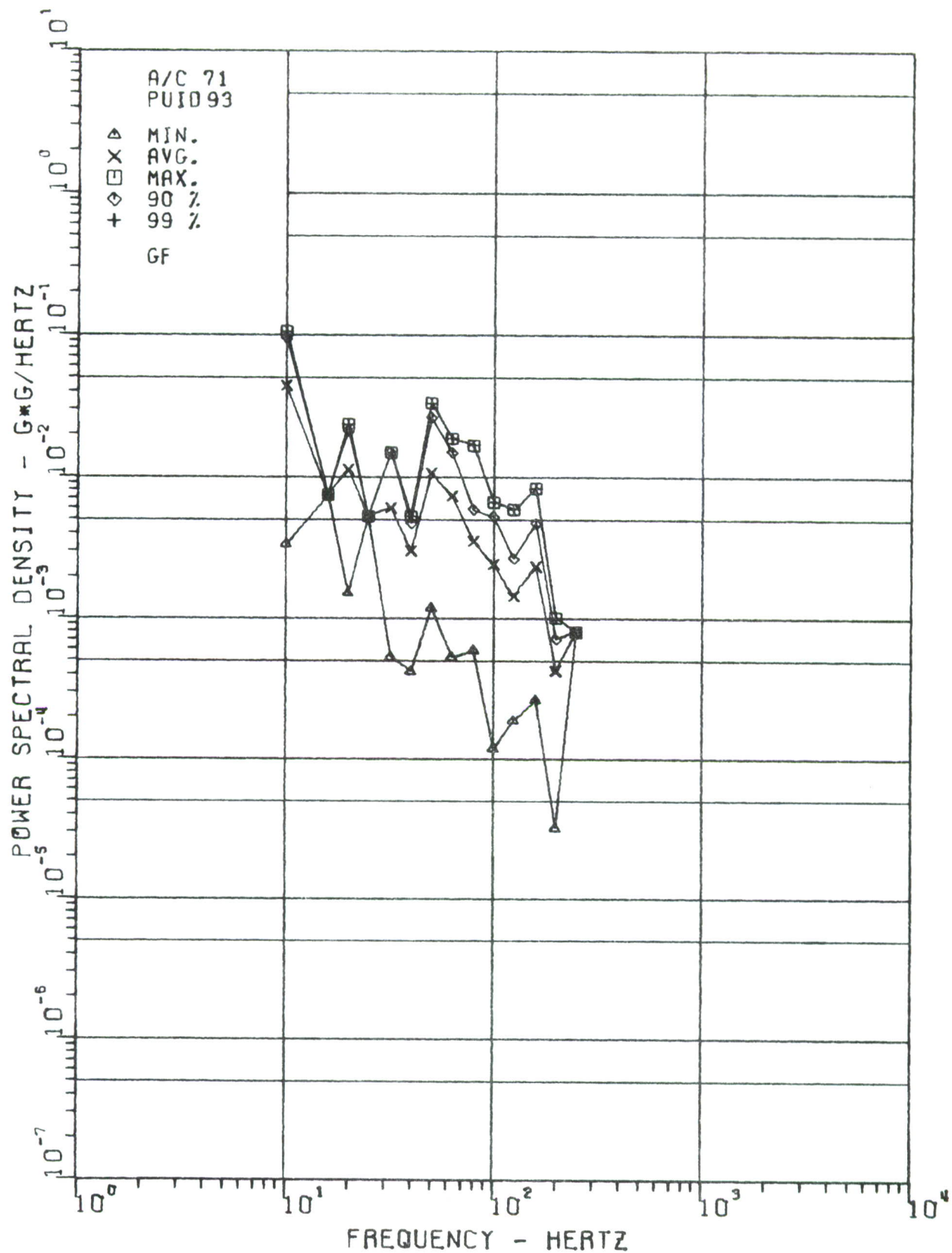


Figure 177. Aft Electrical Compartment near AN/ASN-43 Gyro
Compass, Sta. 284, with Gunfire

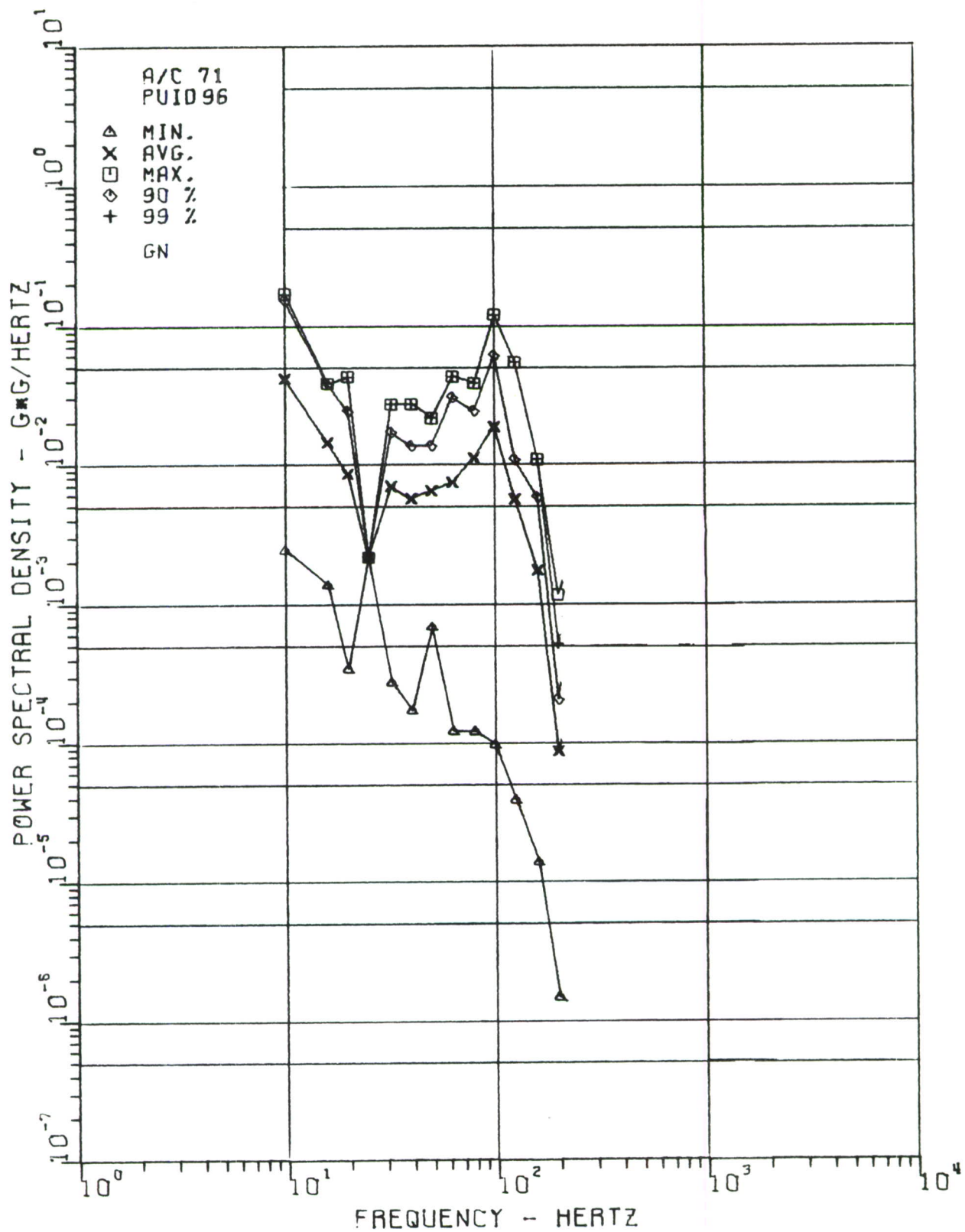


Figure 178. Tail Boom near 90° Gear Box, Sta. 524

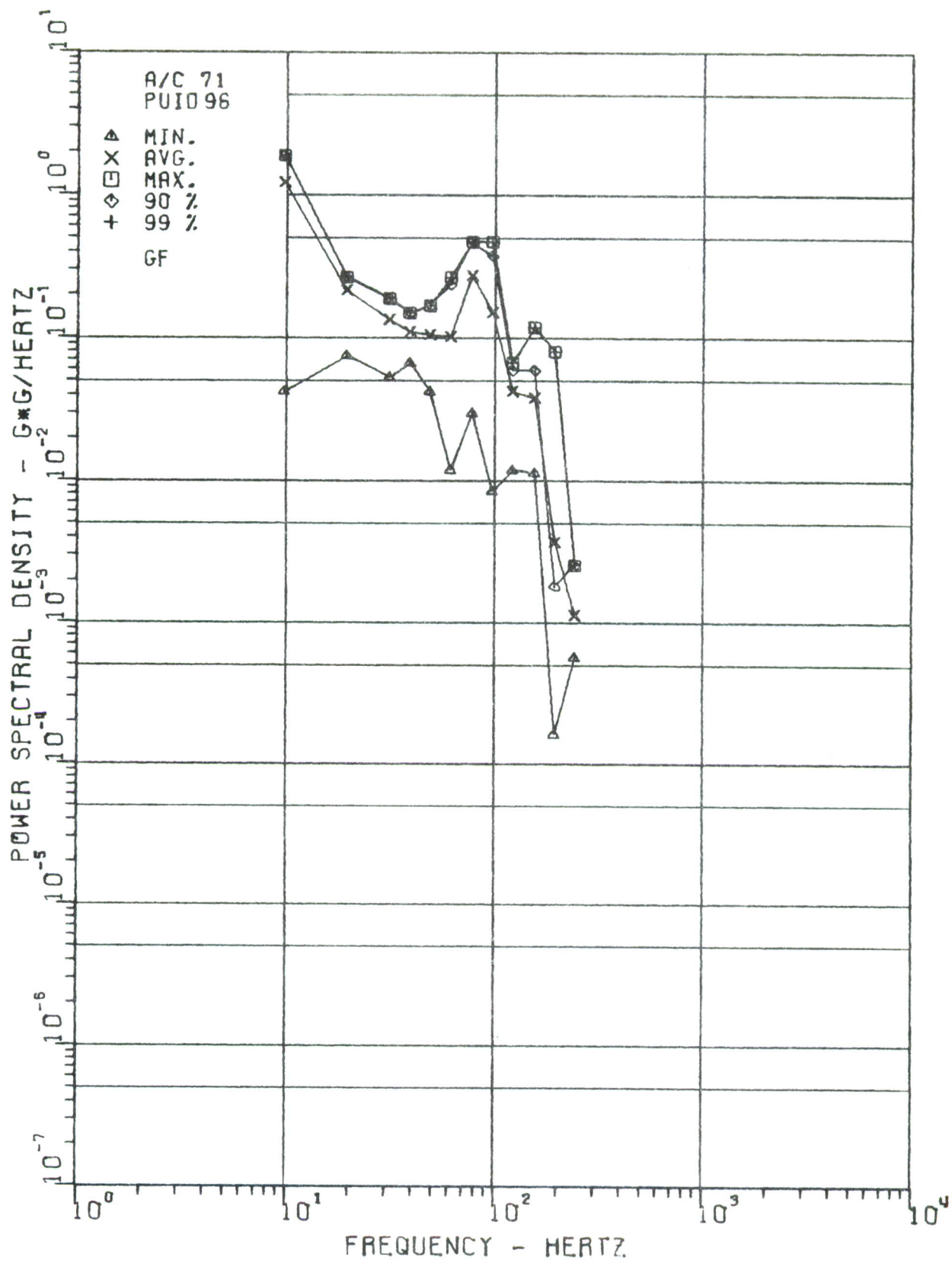


Figure 179. Tail Boom near 90° Gear Box, Sta. 524, with Gunfire

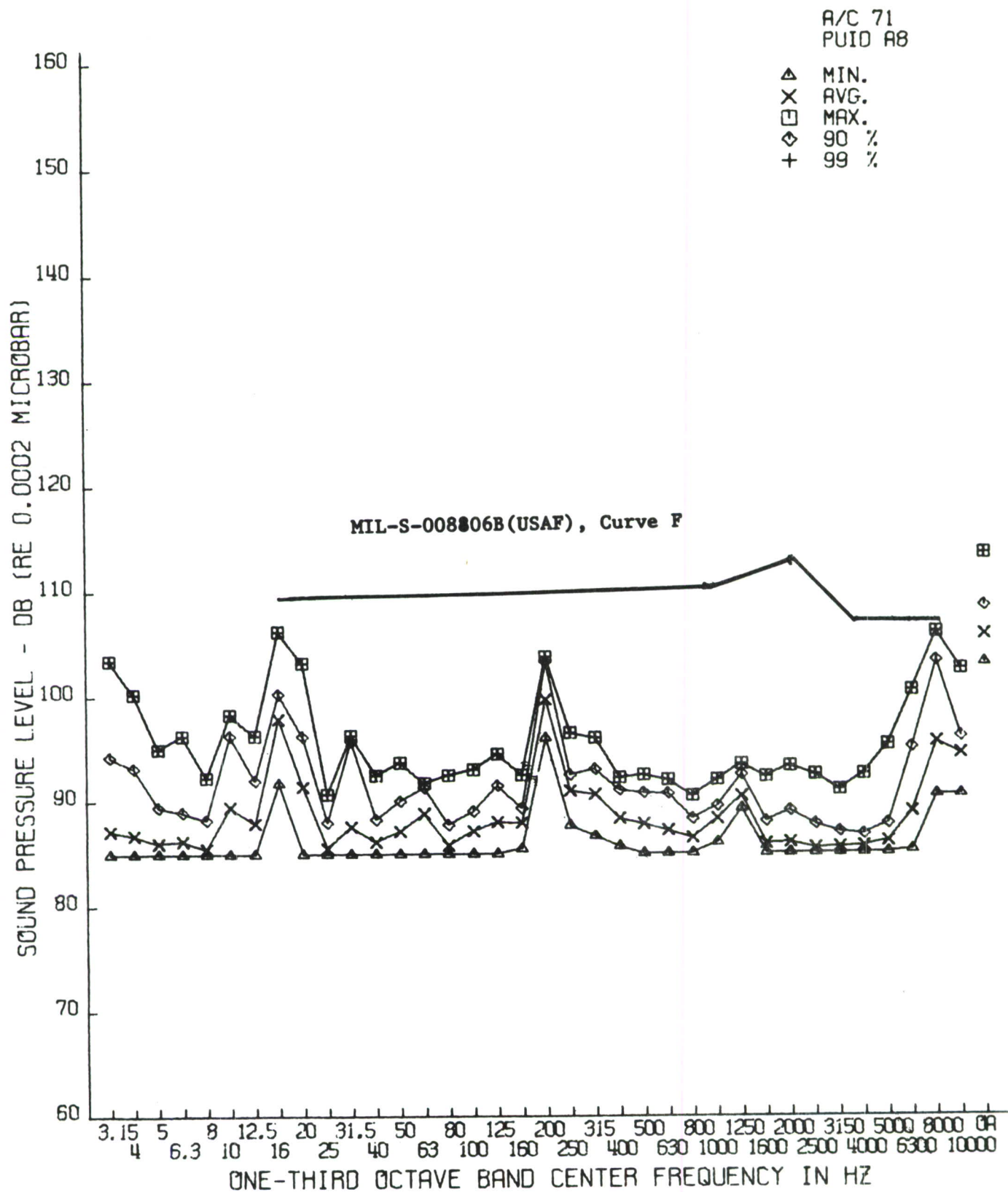


Figure 180. Gunner's Helmet, Sta. 90, Without Gunfire

A/C 71
PUID A8

- △ MIN.
- × AVG.
- MAX.
- ◇ 90 %
- + 99 %

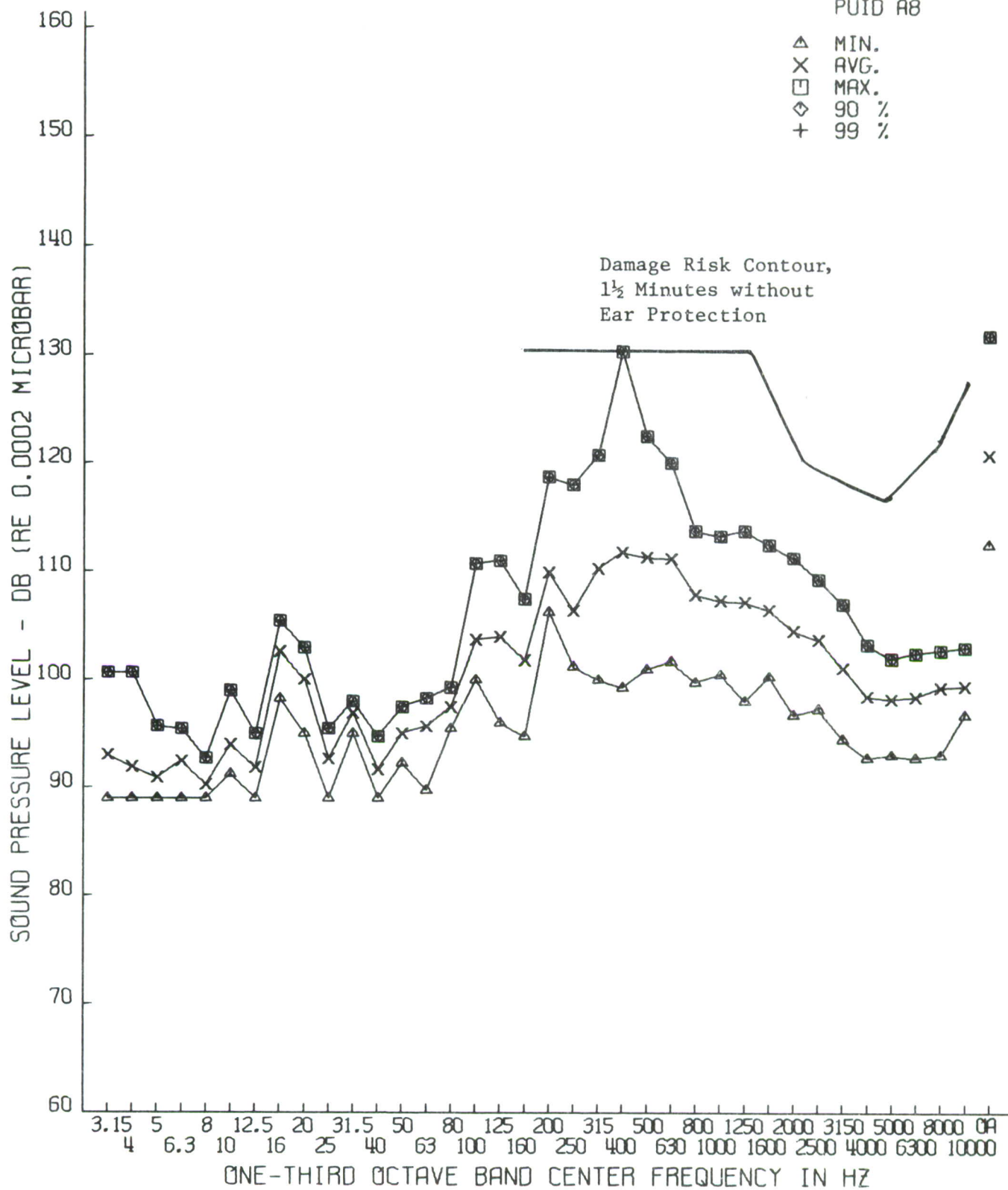


Figure 181. Gunner's Helmet, Sta. 90, With Gunfire

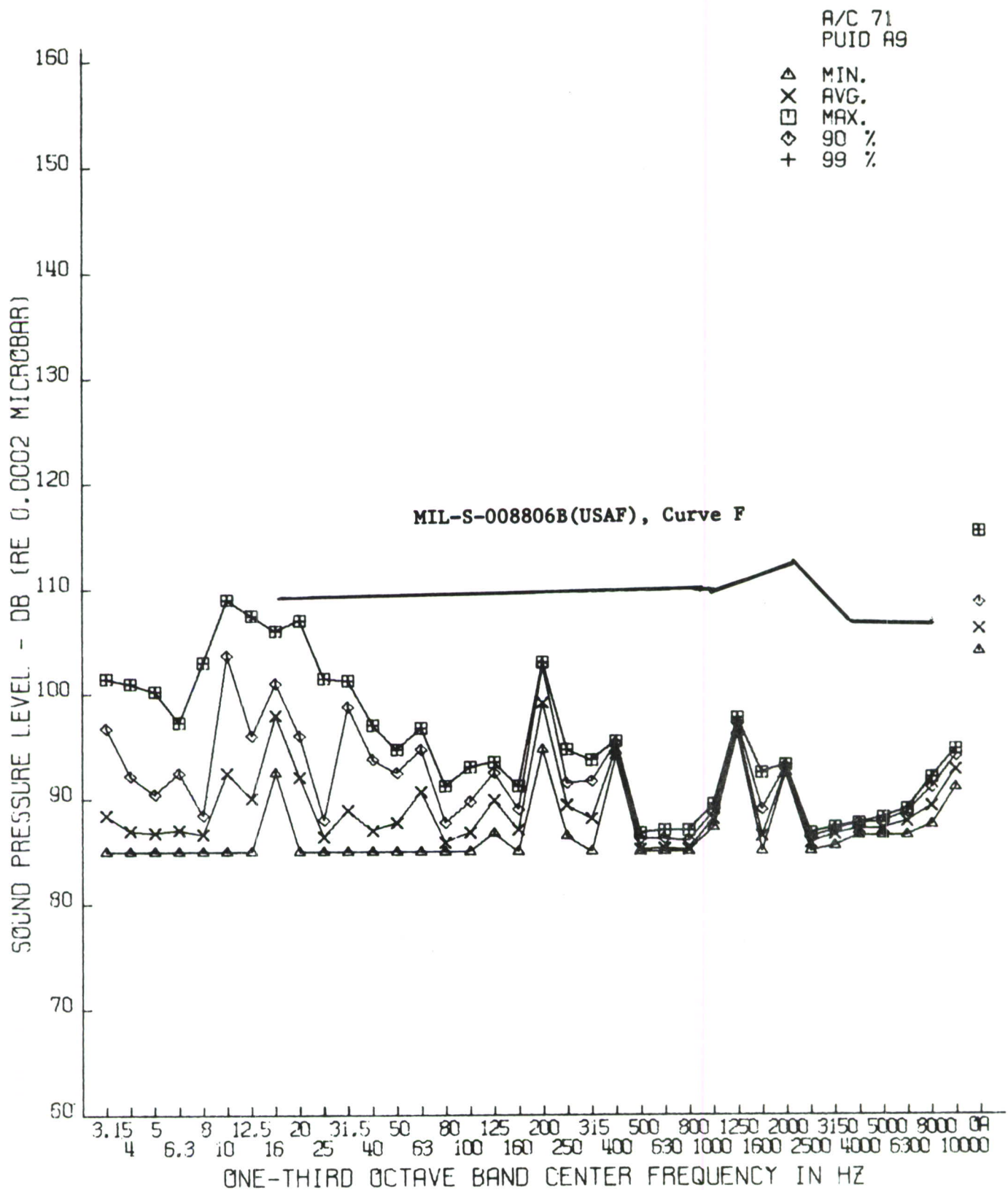


Figure 182. Pilot's Helmet, Sta. 140, Without Gunfire

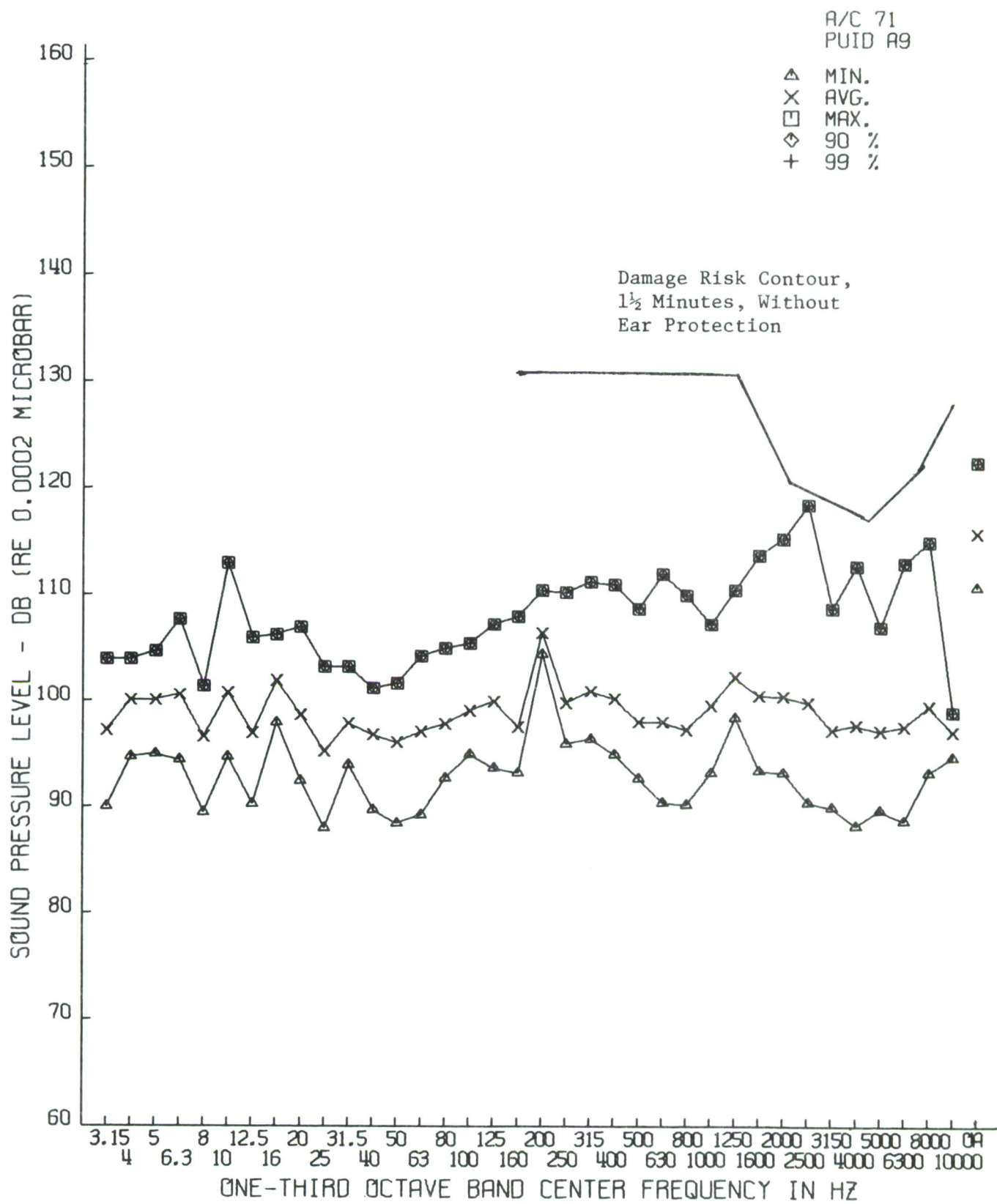


Figure 183. Pilot's Helmet, Sta. 140, With Gunfire

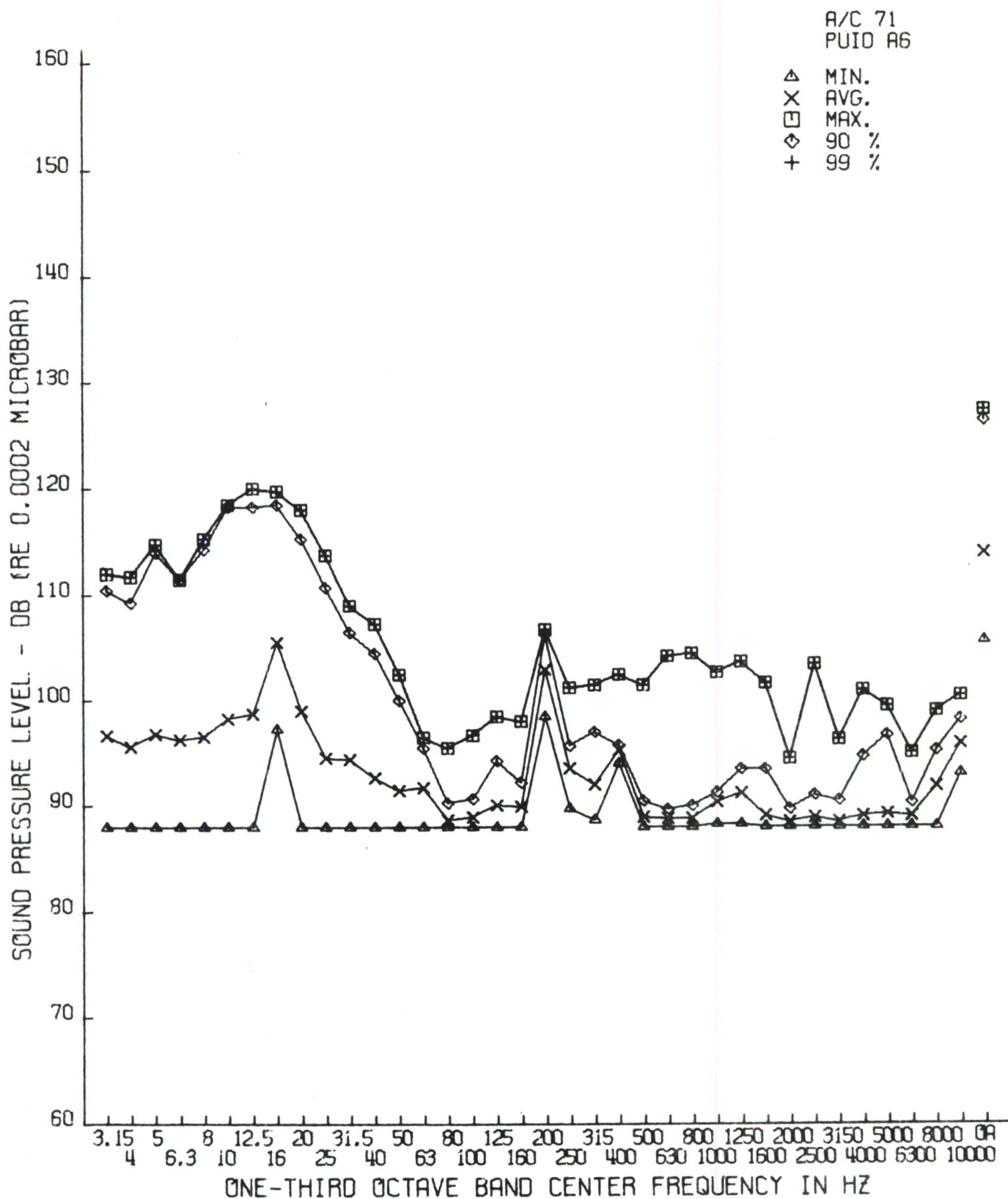


Figure 184. Aft Electrical Comp., Sta. 284, without Gunfire

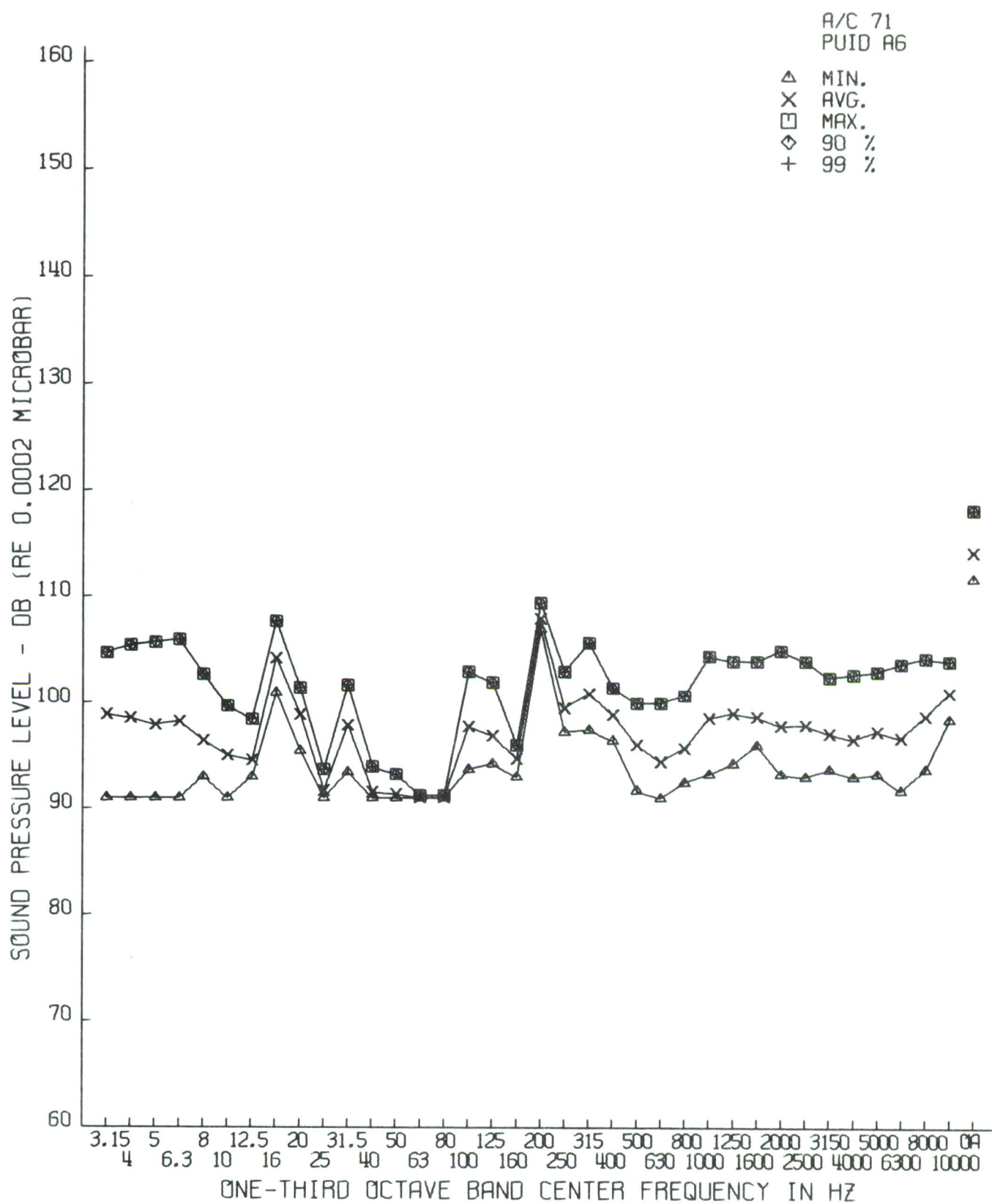


Figure 185. Aft Electrical Comp., Sta. 284, with Gunfire

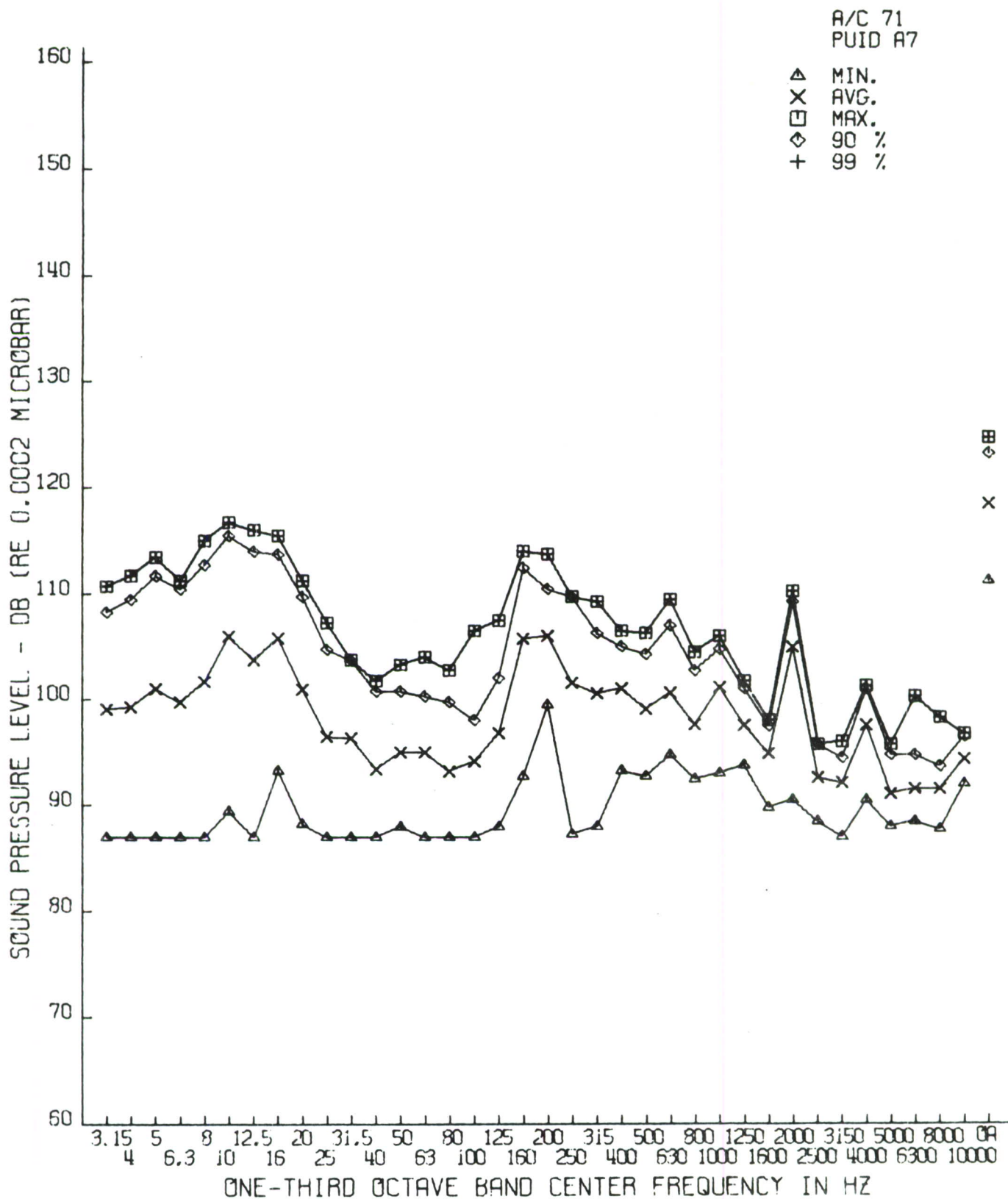


Figure 186. Radio Compartment, Sta. 390, without Gunfire

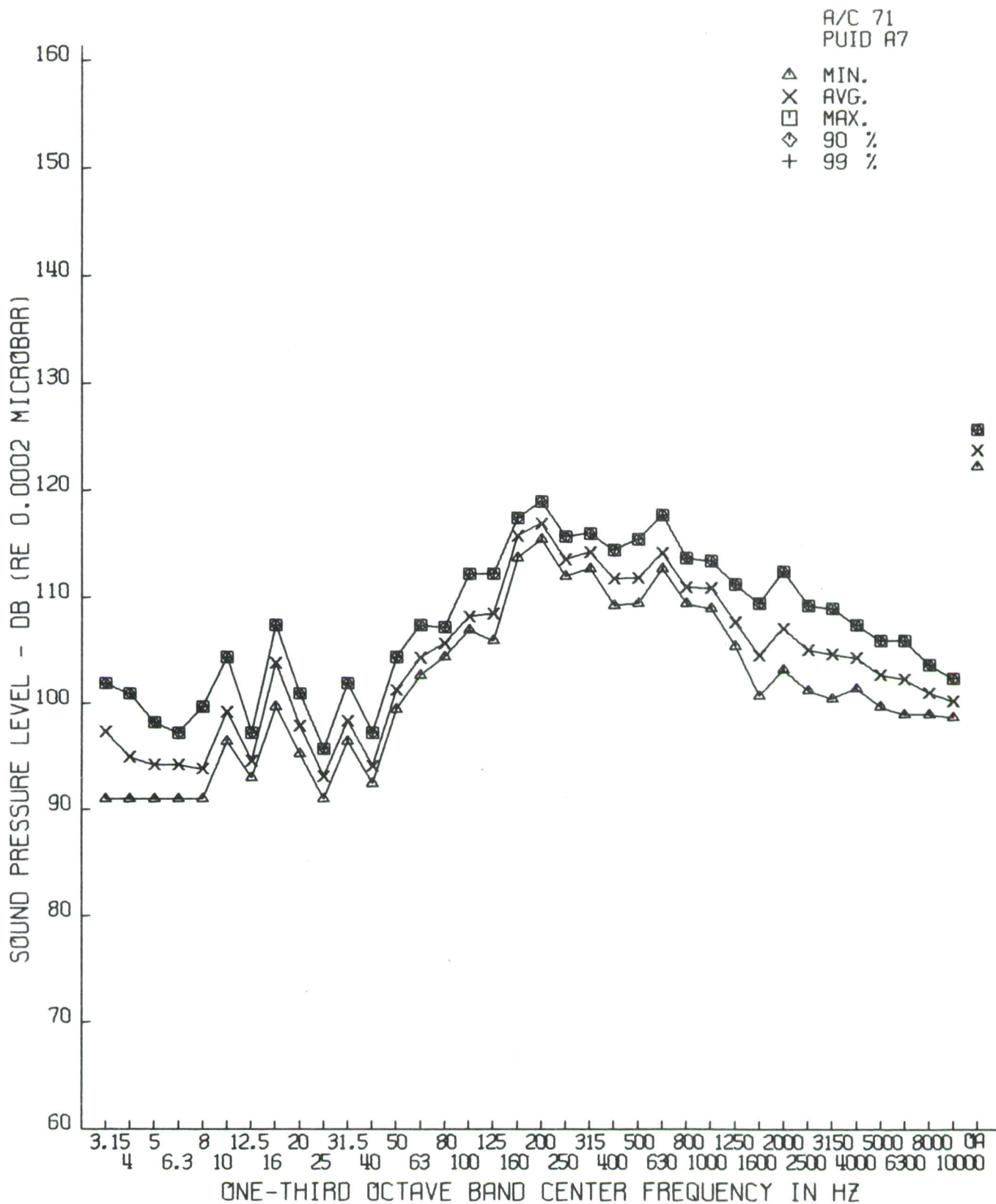


Figure 187. Radio Compartment, Sta. 390, with Gunfire

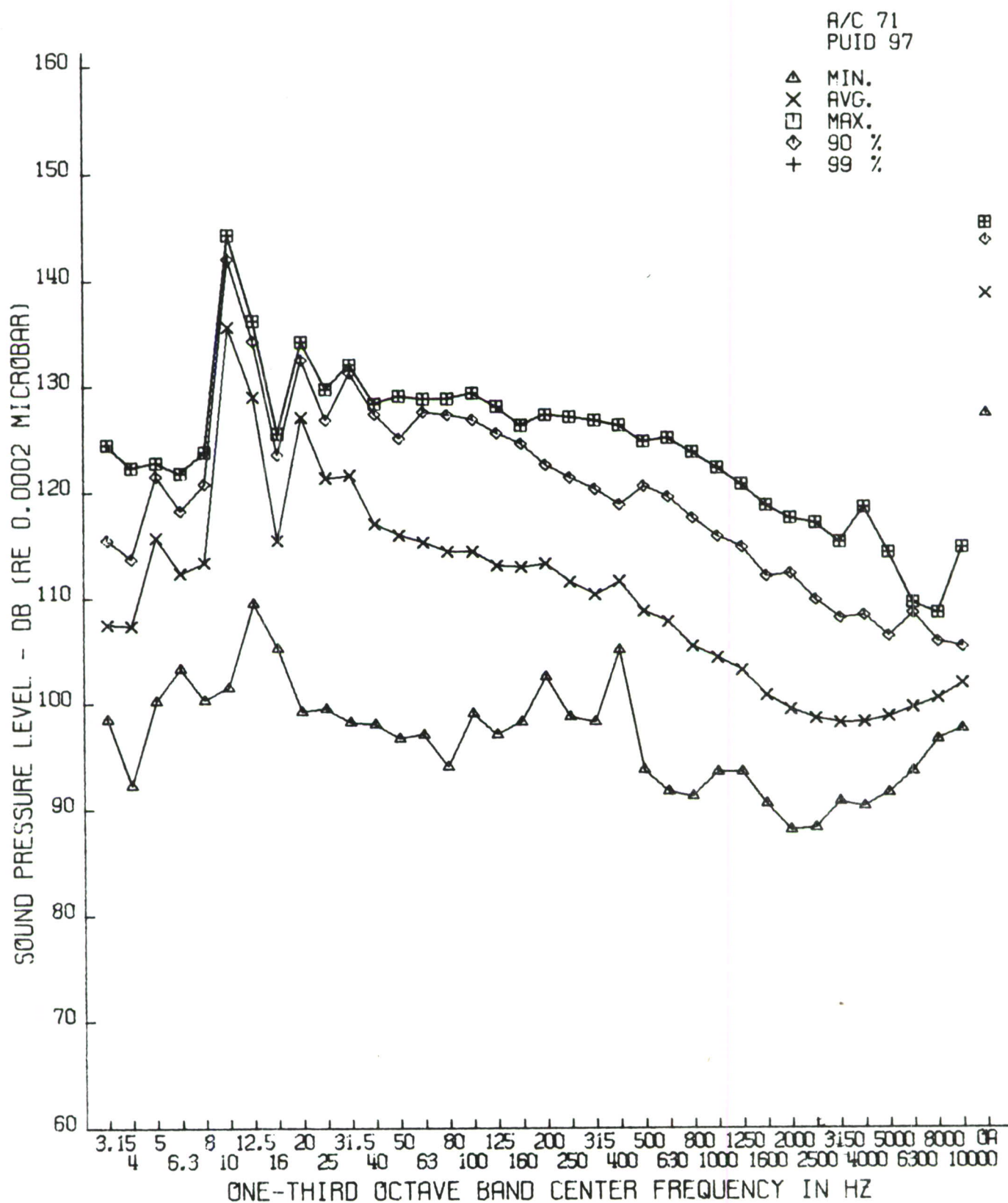


Figure 188. Canopy Top, Outside, Sta. 58, without Gunfire

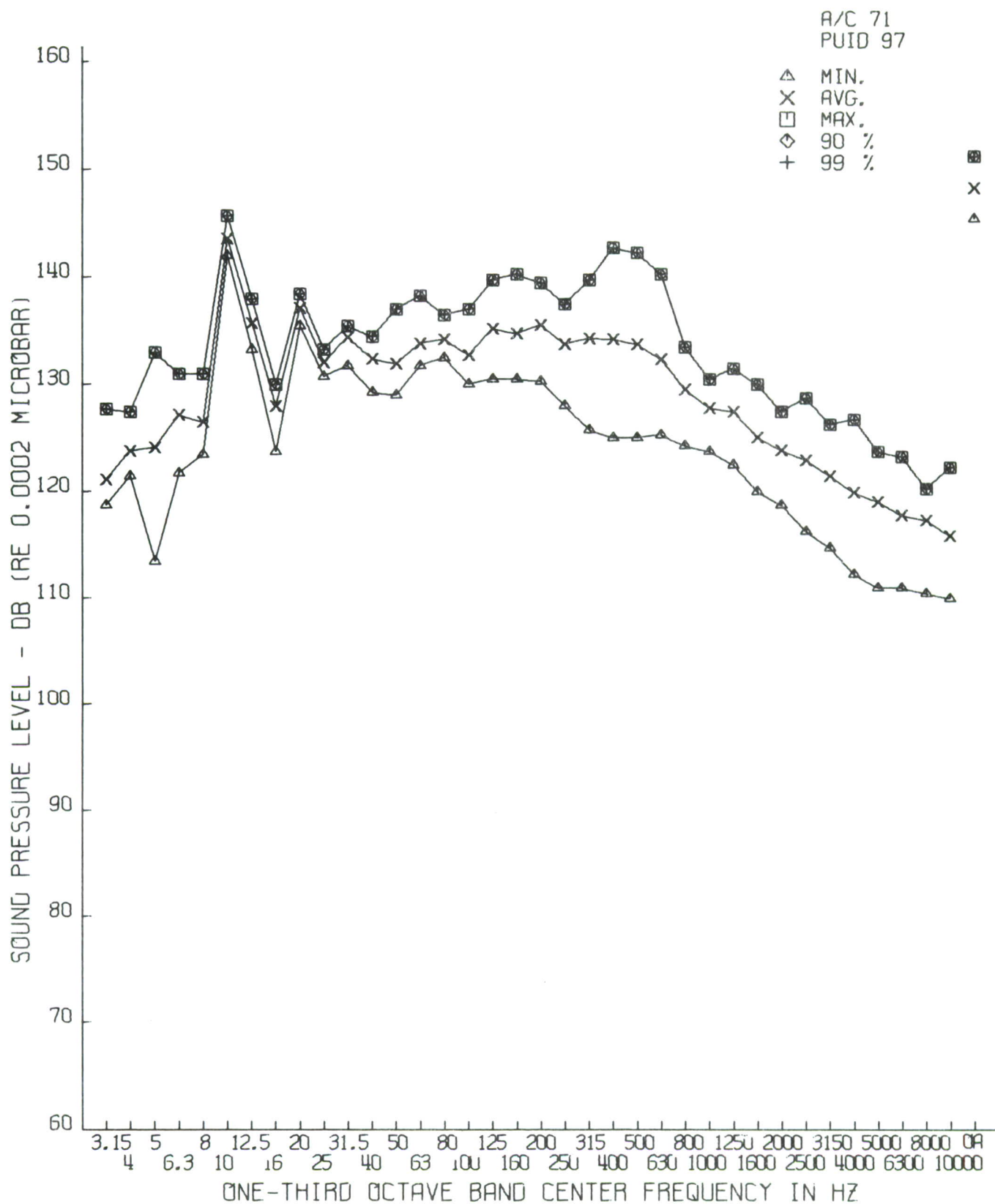


Figure 189. Canopy Top, Outside, Sta. 58, with Gunfire

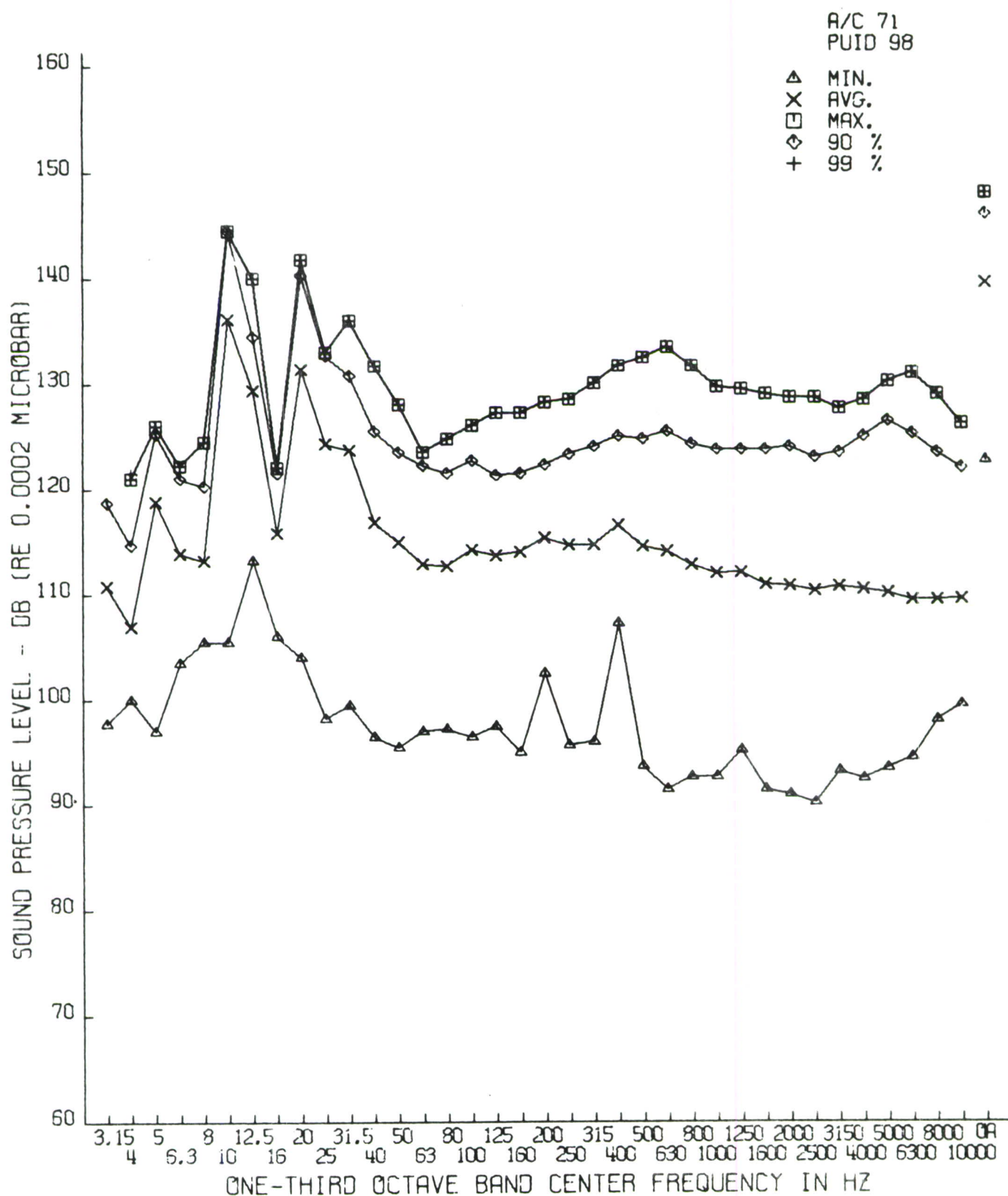


Figure 190. Canopy Top, Outside, Sta. 103, without Gunfire

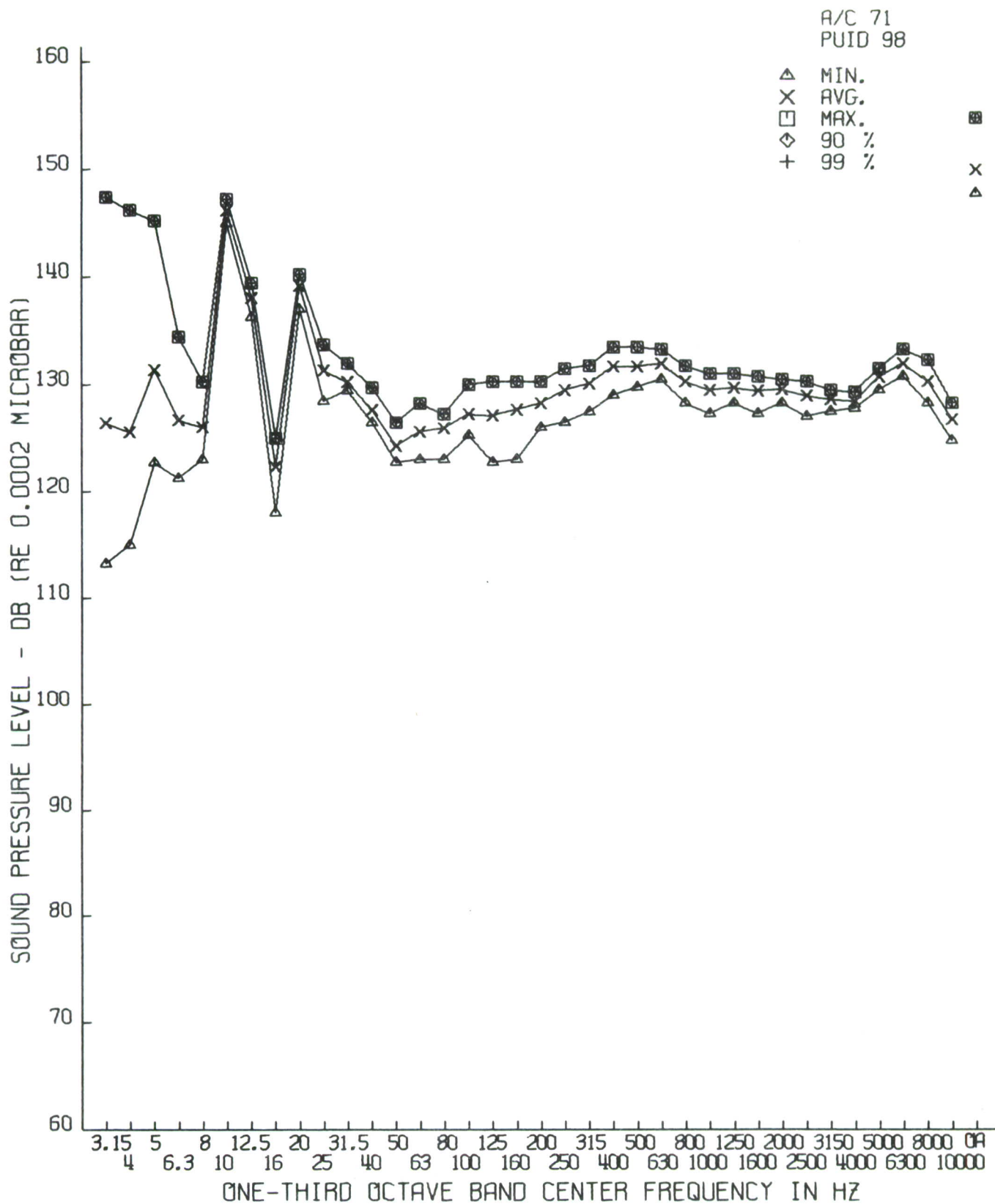


Figure 191. Canopy Top, Outside, Sta. 103, with Gunfire

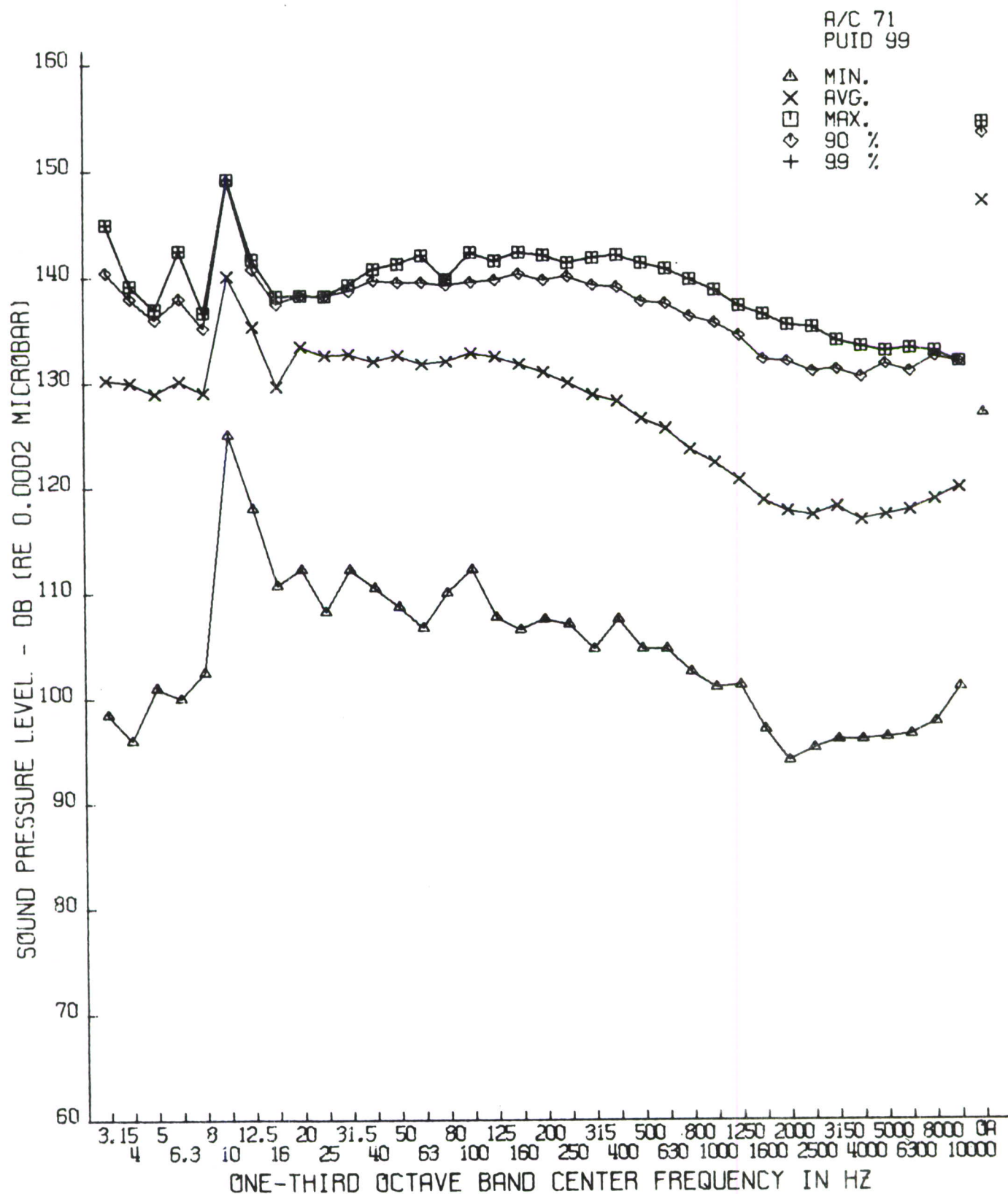


Figure 192. Tailboom Top, Outside, Sta. 333, without Gunfire

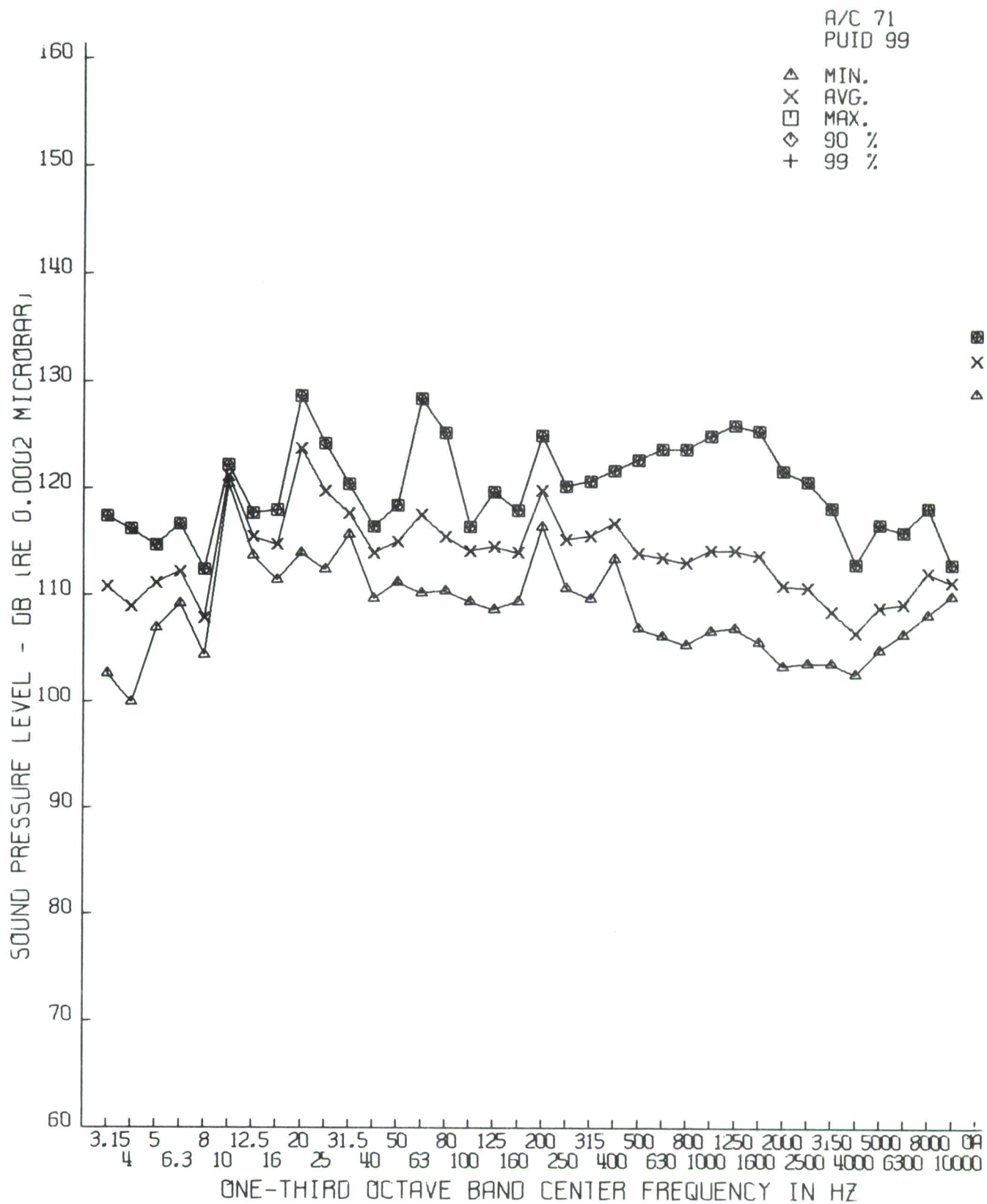


Figure 193. Tailboom Top, Outside, Sta. 333, with Gunfire

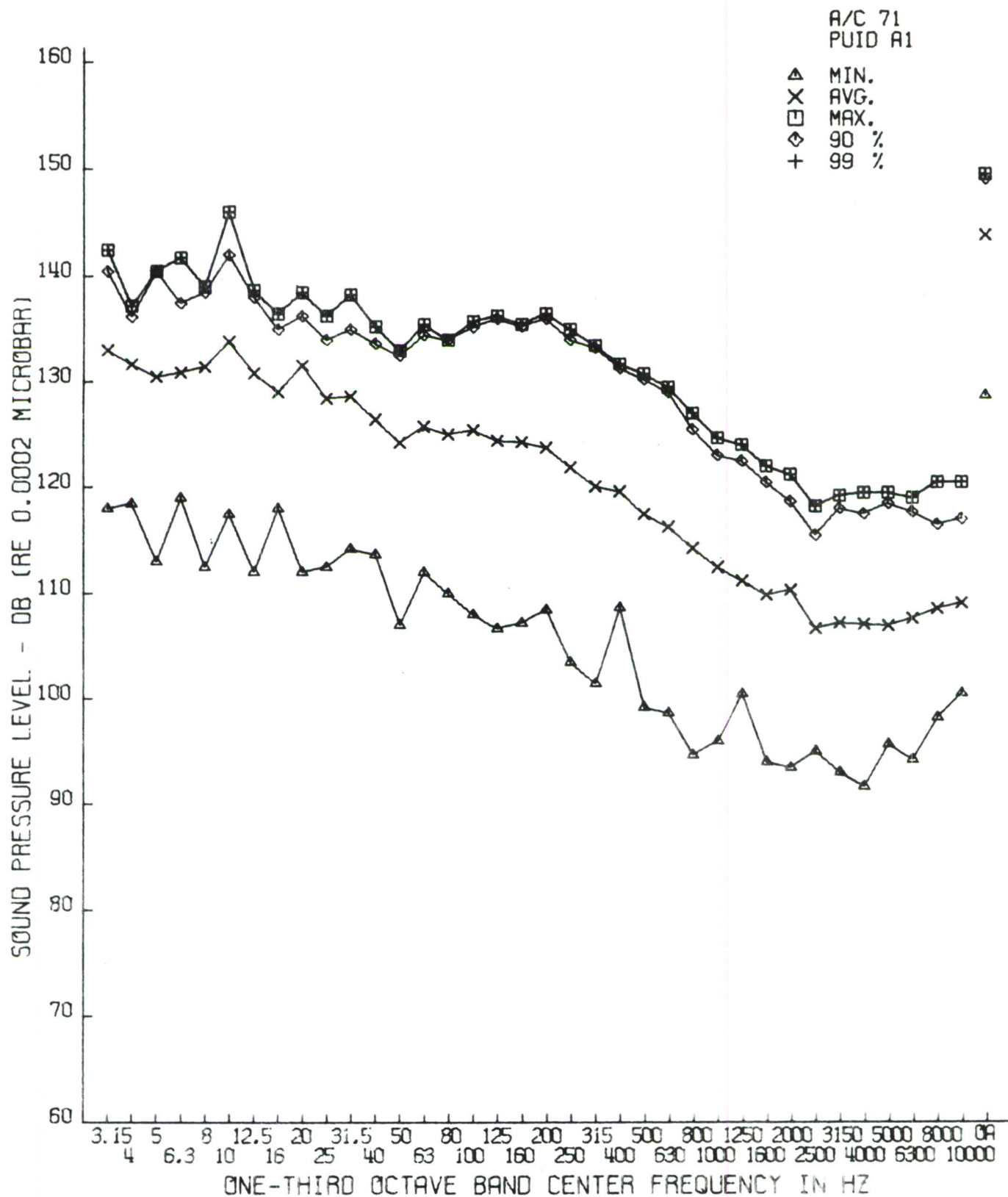


Figure 194. Tailboom Top, Outside, Sta. 393, without Gunfire

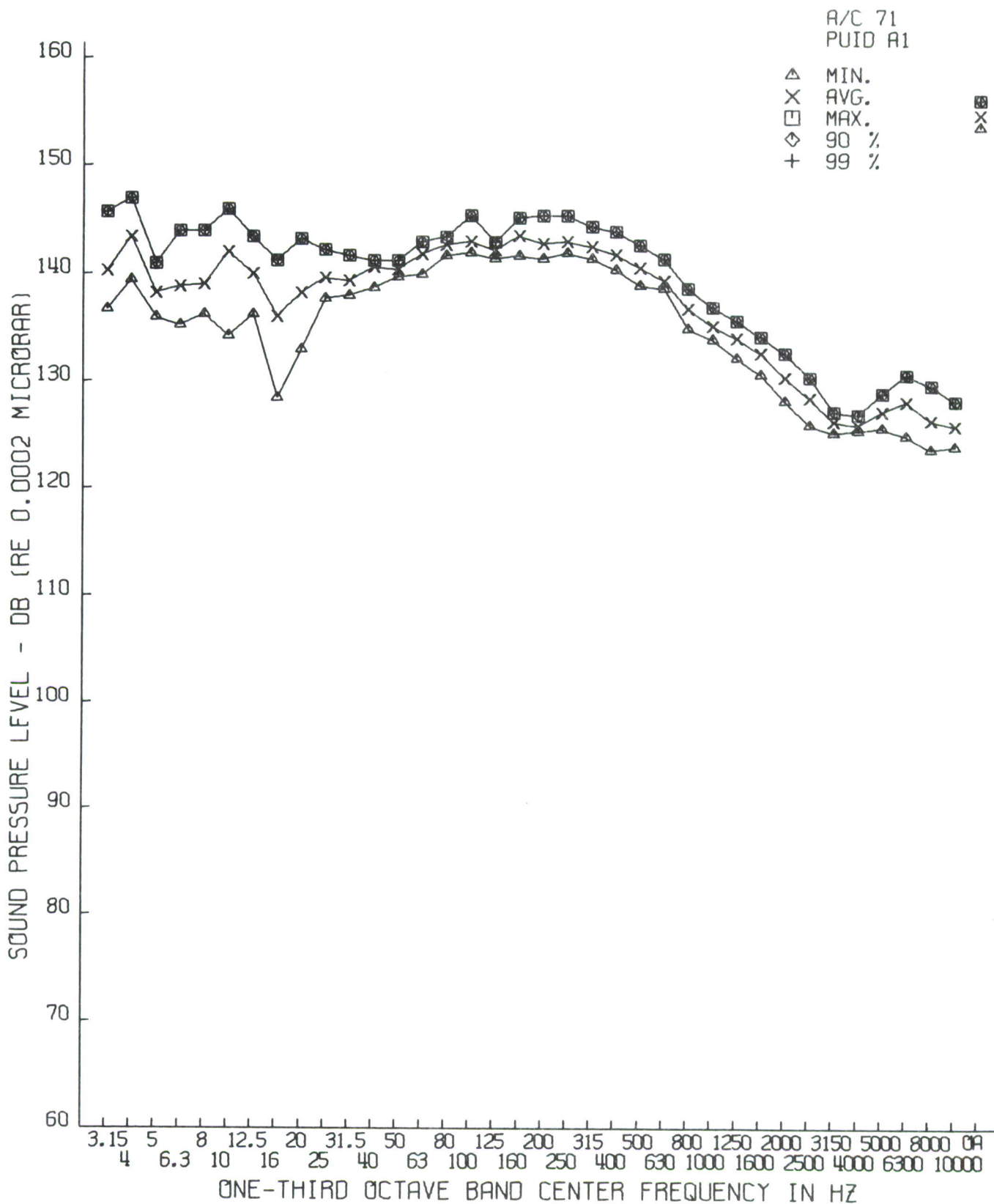


Figure 195. Tailboom Top, Outside, Sta. 393, with Gunfire

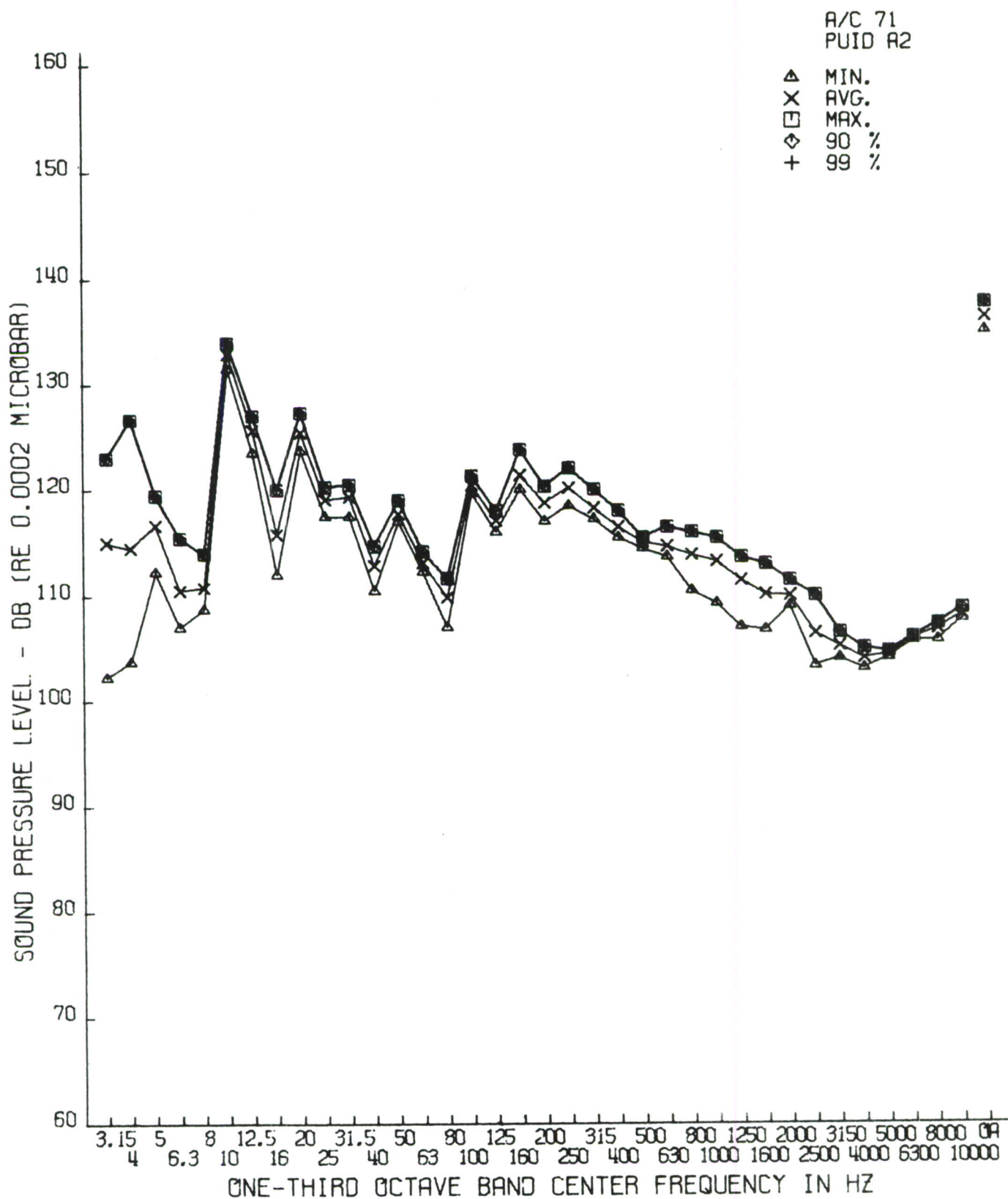


Figure 196. Tailboom Top, Outside, Sta. 458, without Gunfire

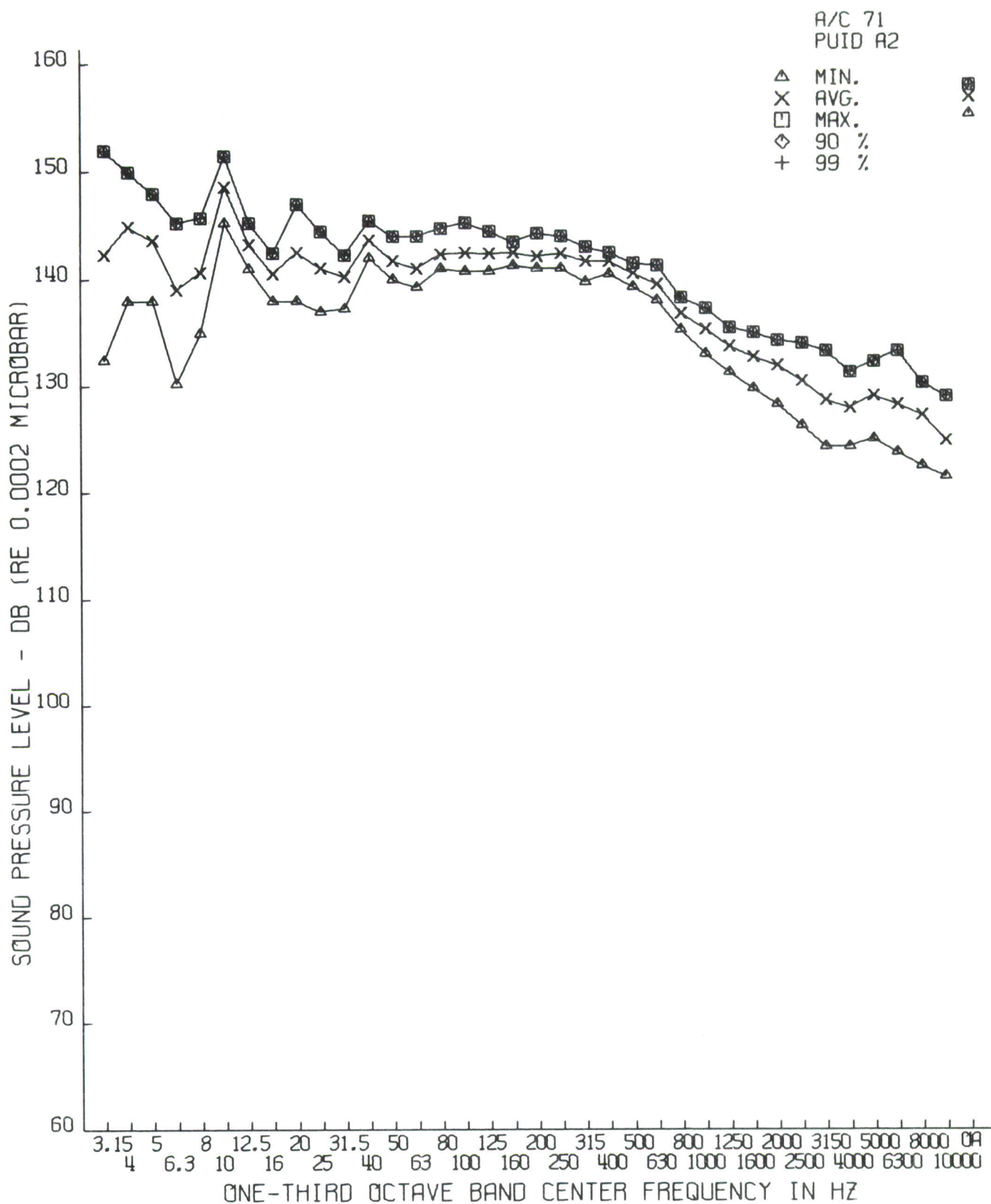


Figure 197. Tailboom Top, Outside, Sta. 458, with Gunfire

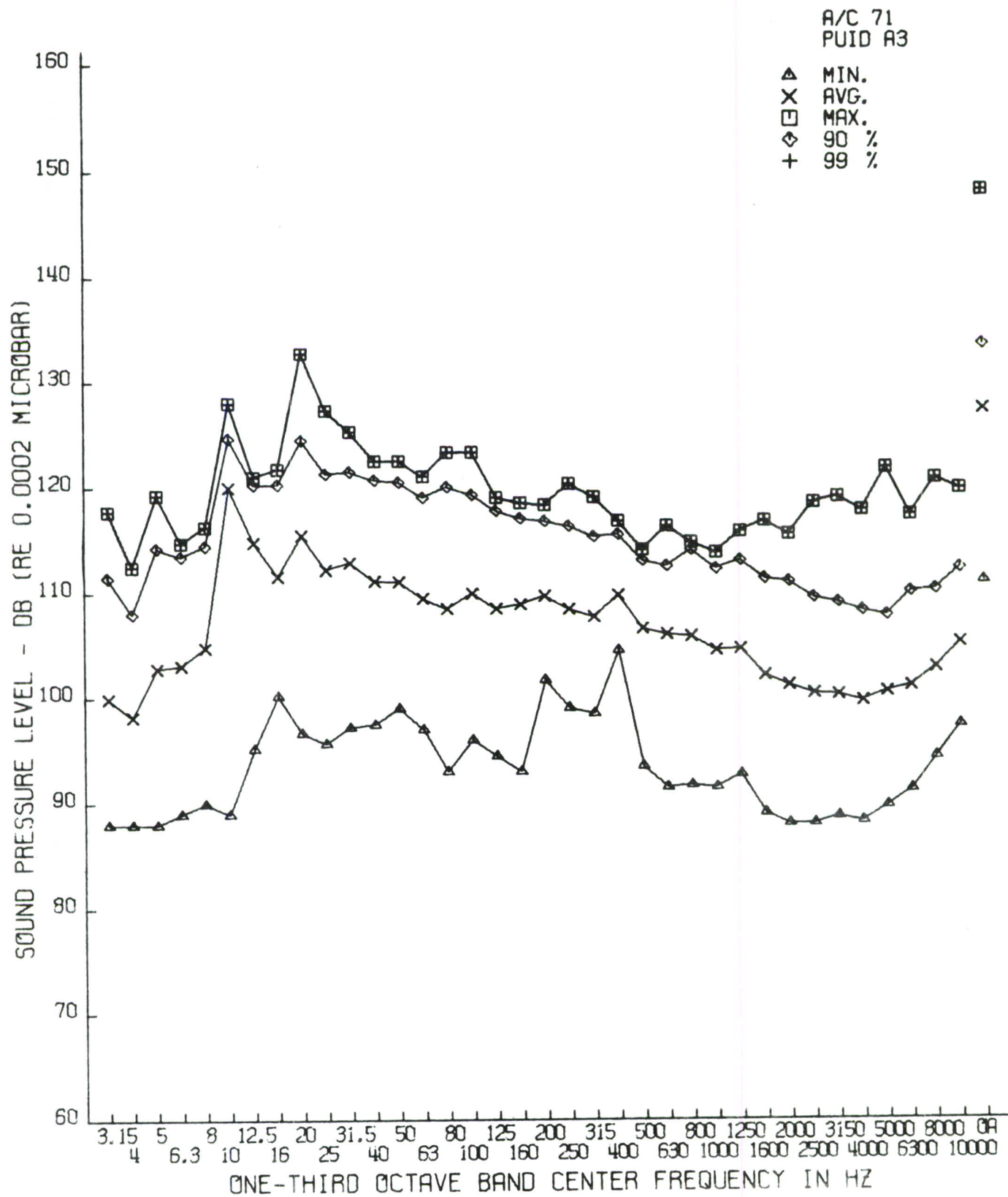


Figure 198. Nose, Bottom, Outside, Sta. 54, without Gunfire

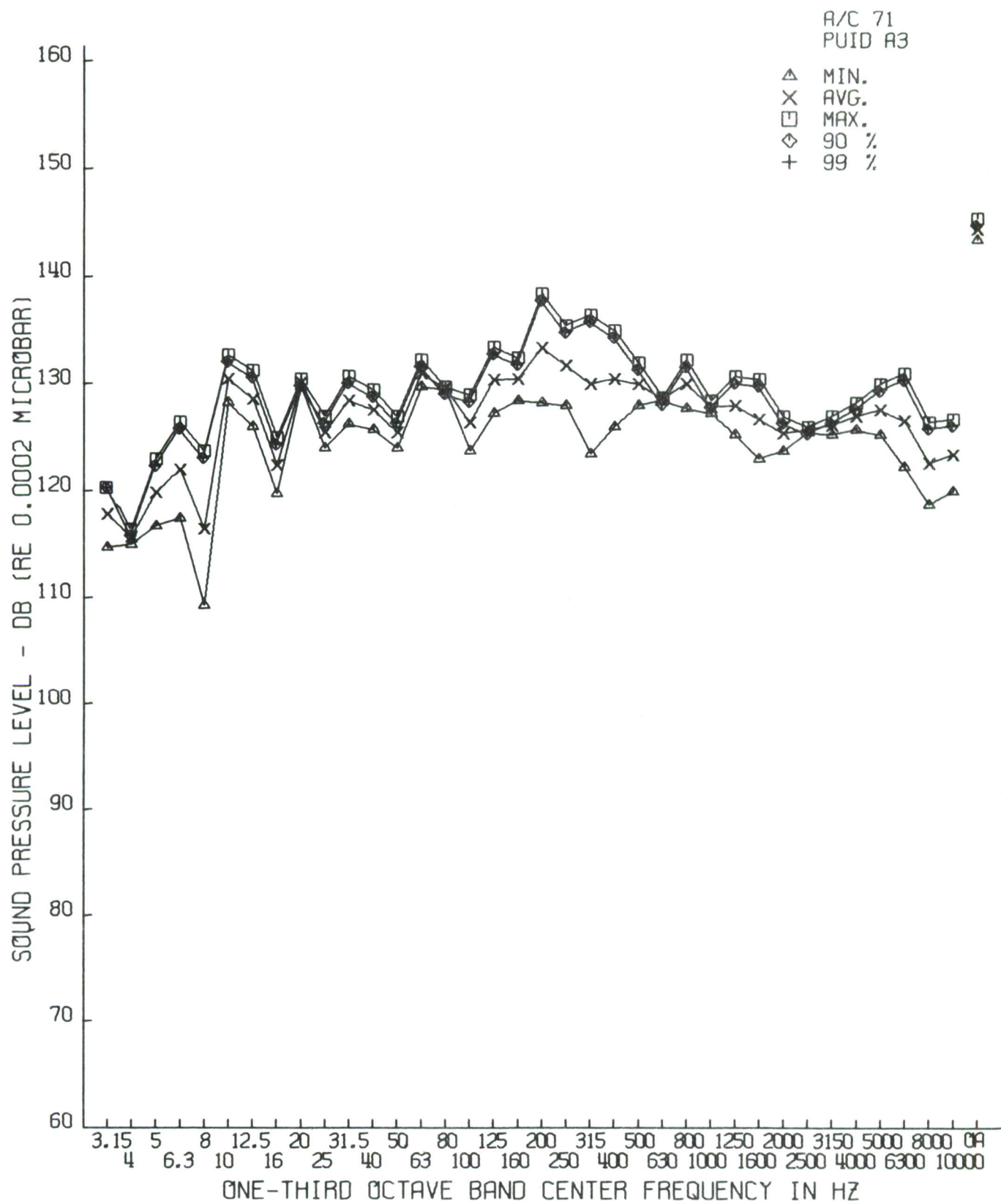


Figure 199. Nose, Bottom, Outside, Sta. 54, with Gunfire

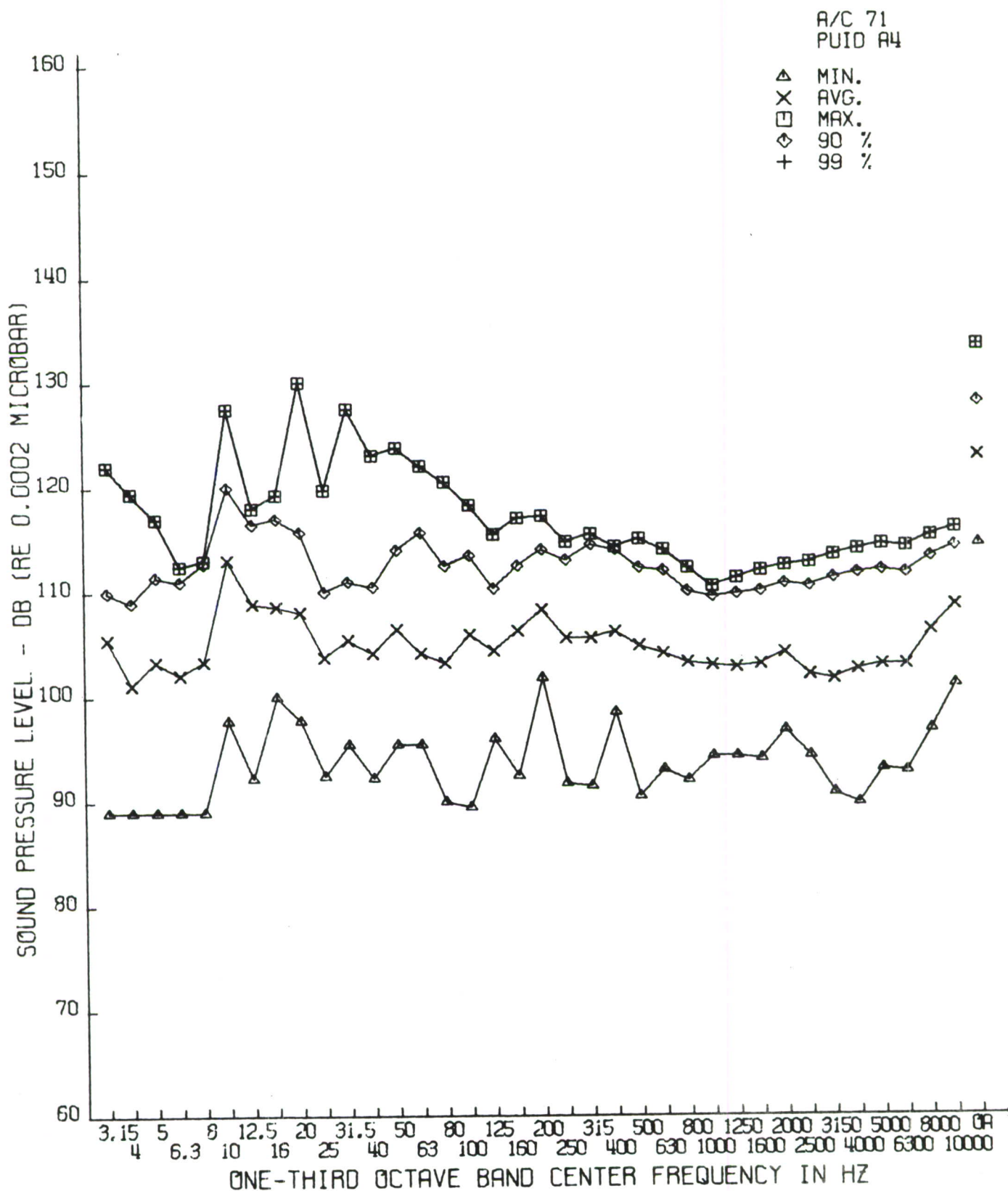


Figure 200. Wing, Right, Outside, Sta. 184, without Gunfire

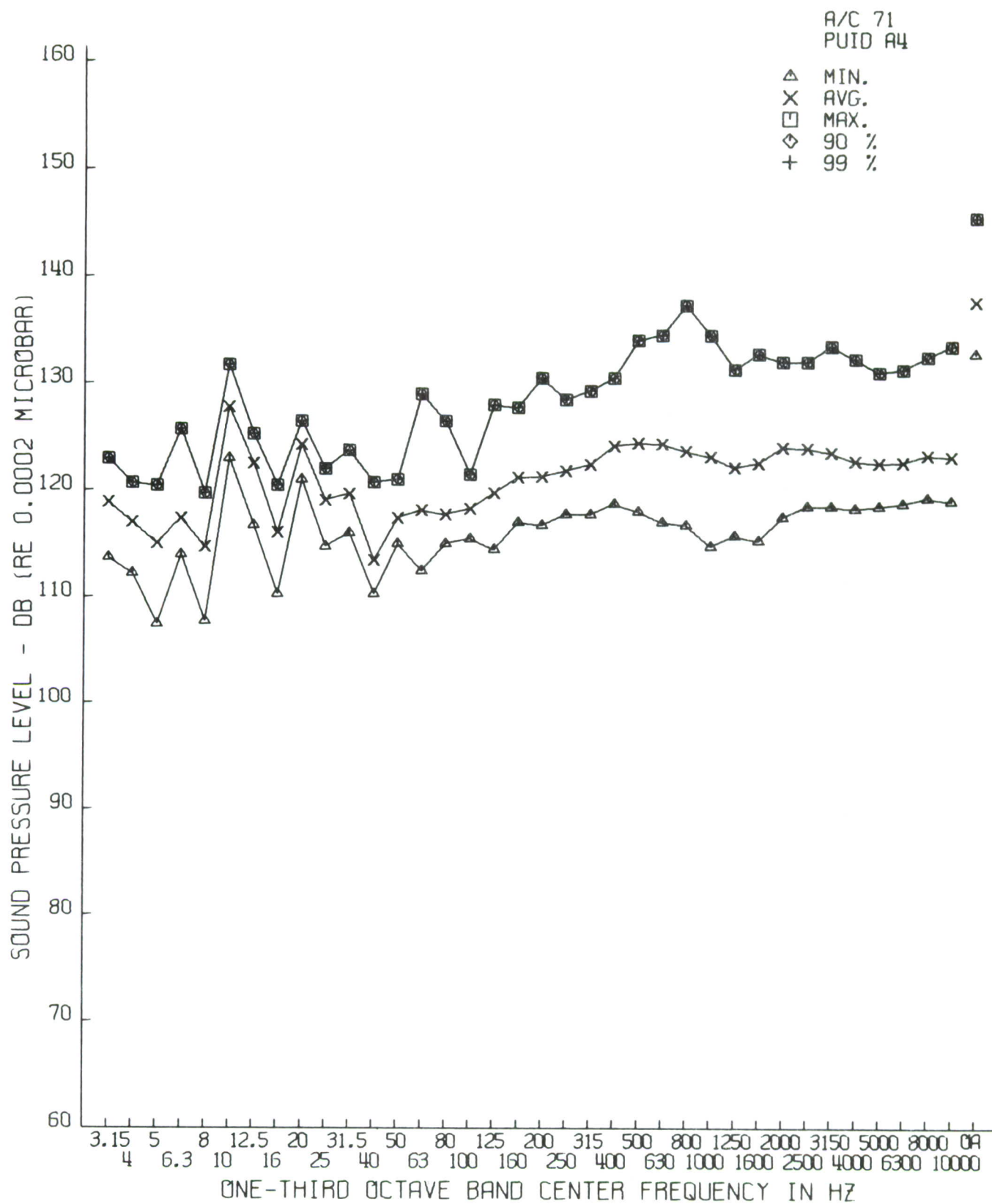


Figure 201. Wing, Right, Outside, Sta. 184, with Gunfire

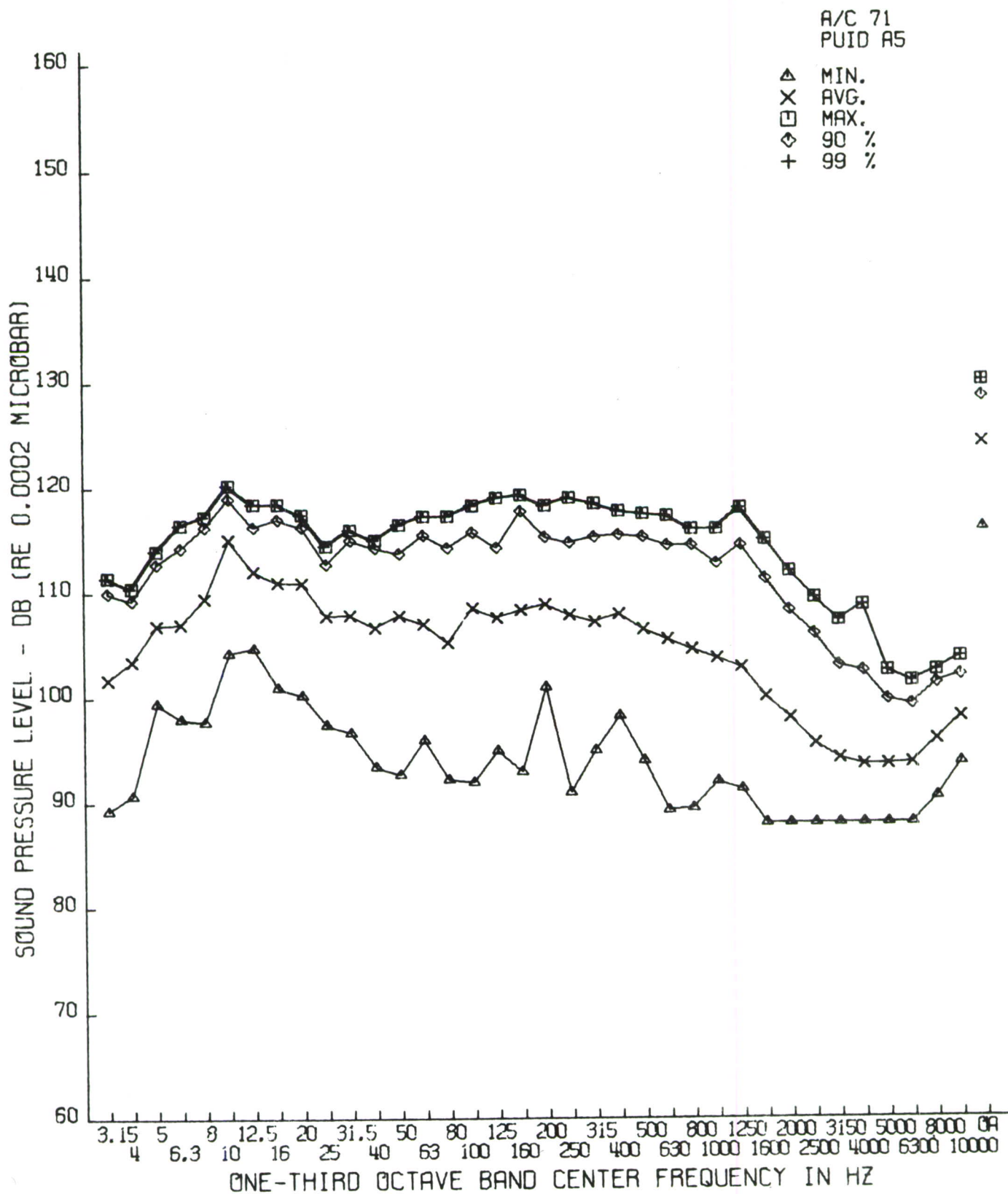


Figure 202. Below Aft Elec. Comp., Outside, Sta. 287, without Gunfire

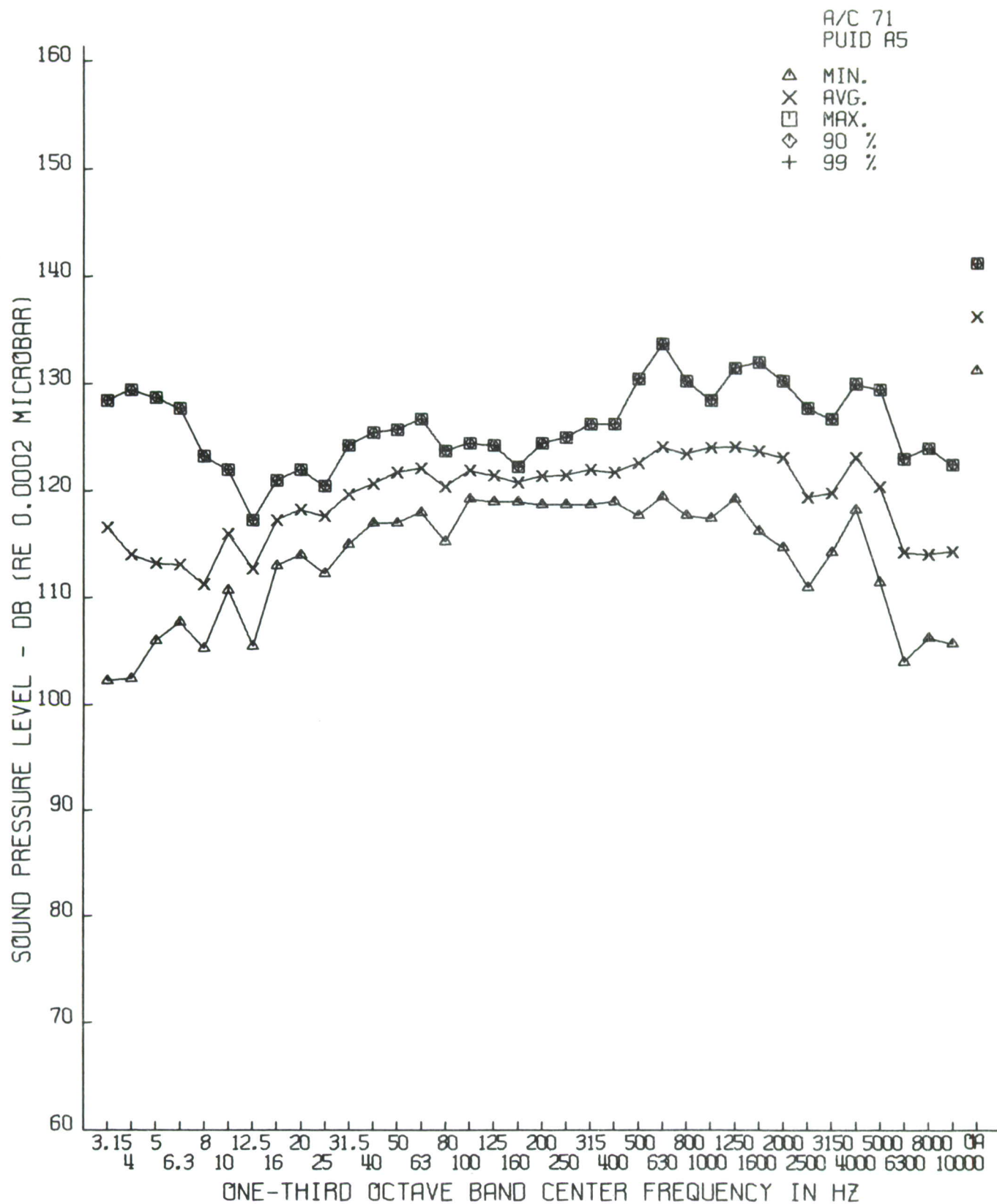


Figure 203. Below Aft Elec. Comp., Outside, Sta. 287, with Gunfire